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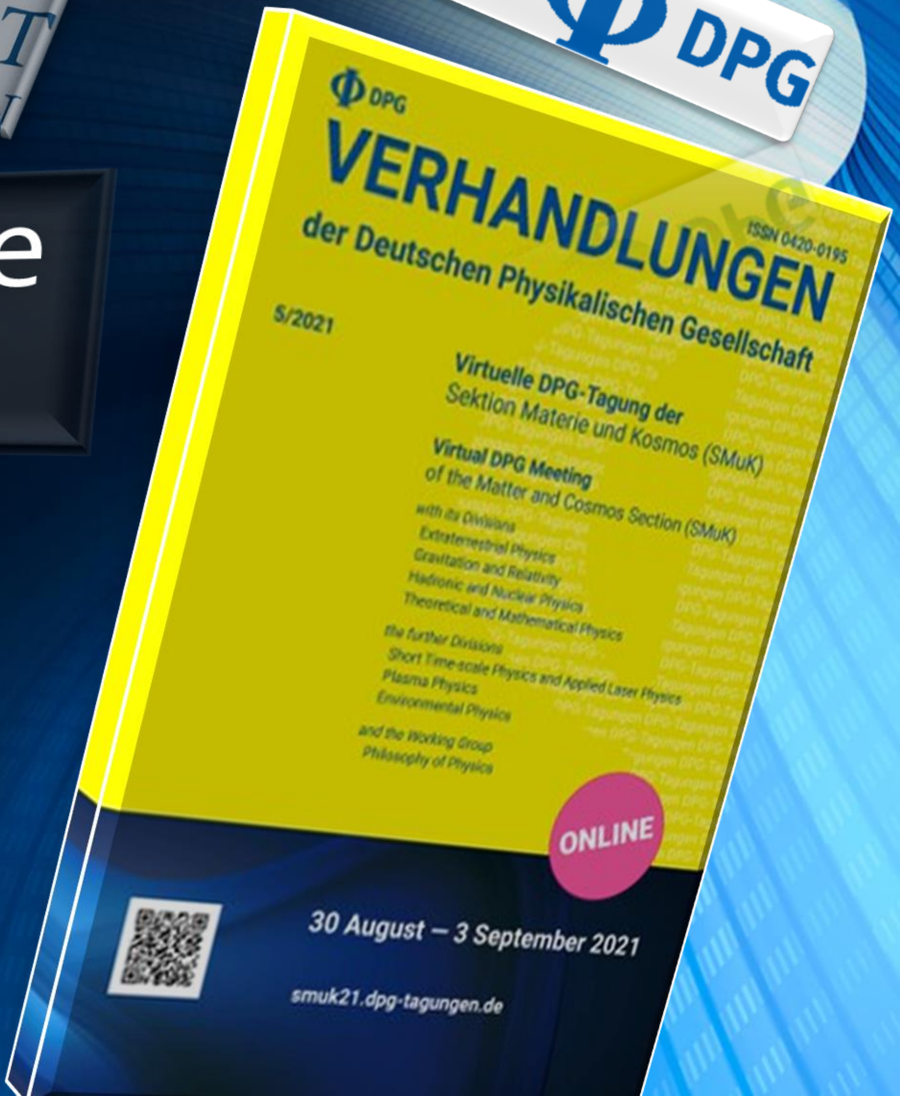
Deutsche Physikalische Gesellschaft DPG

On the properties of metastable hypermassive hybrid stars



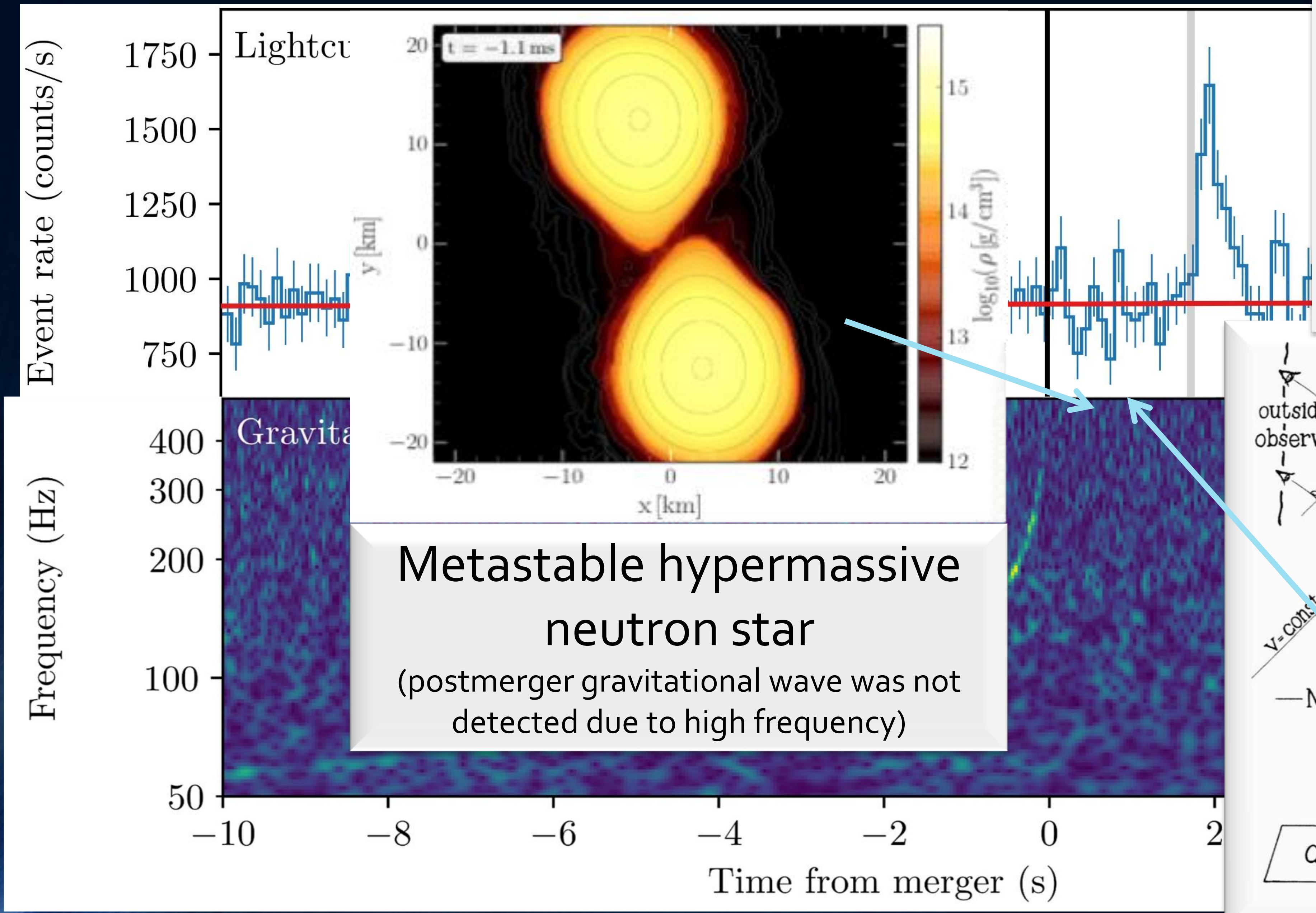
<u>*DPG-Frühjahrstagung*</u>

Fachverband: Gravitation und Relativitätstheorie

31.08.2021, 15:00

In collaboration with Lukas Weih, Elias R. Most, Jens Papenfort, Luke Bovard, Gloria Montana, Laura Tolos, Jan Steinheimer, Anton Motornenko, Veronica Dexheimer, Horst Stöcker, and Luciano Rezzolla

Gravitational Wave GW170817 and Gamma-Ray Emission GRB170817A

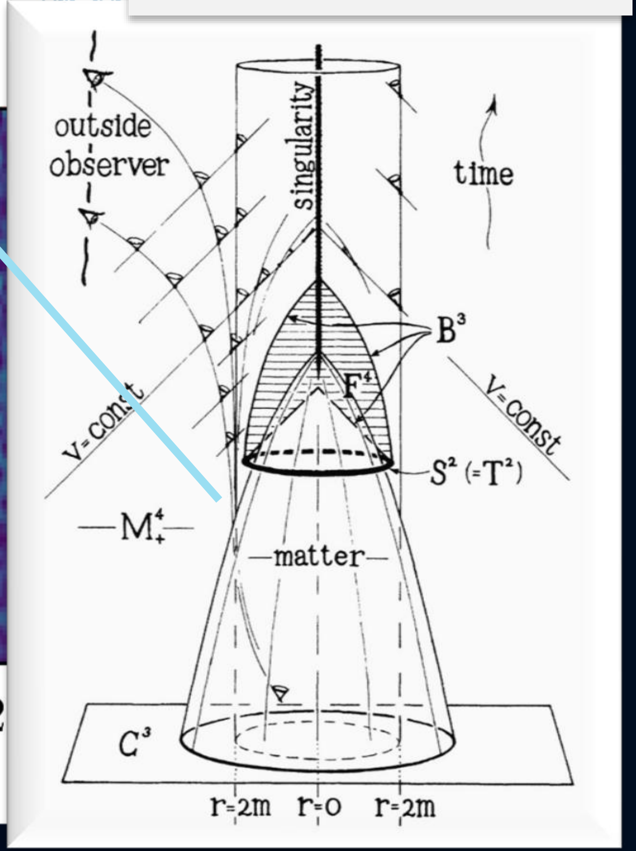


Metastable hypermassive neutron star

(postmerger gravitational wave was not detected due to high frequency)

Gravitational collapse and formation of the black hole

Self-drawn space-time diagram by R.Penrose (1965)



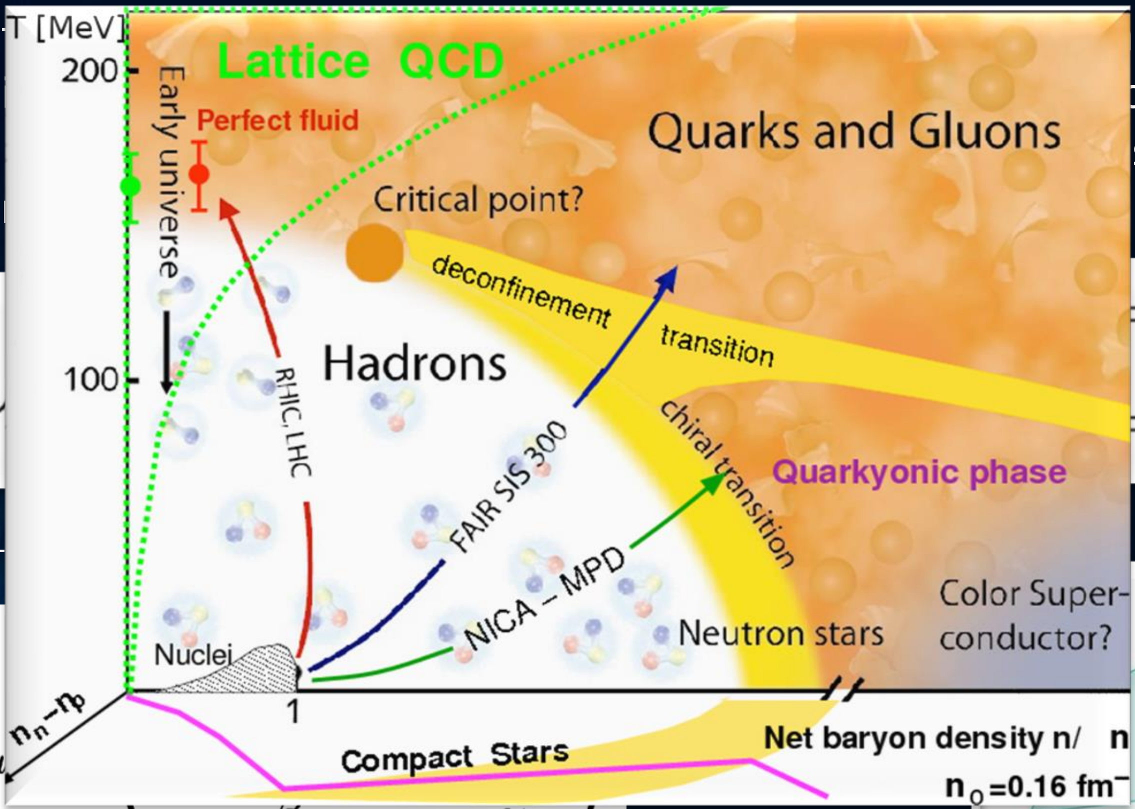
Numerical Relativity and Relativistic Hydrodynamics of Binary Neutron Star Mergers

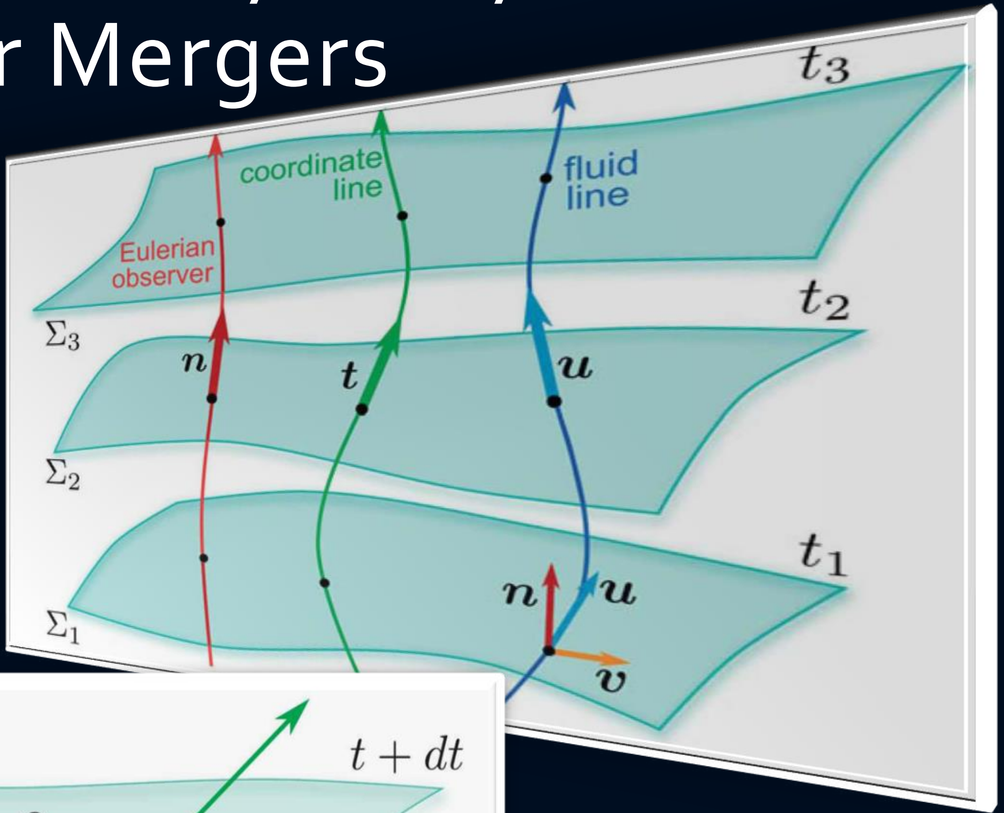
Eins… l
relat… ction
with … s of
neut…

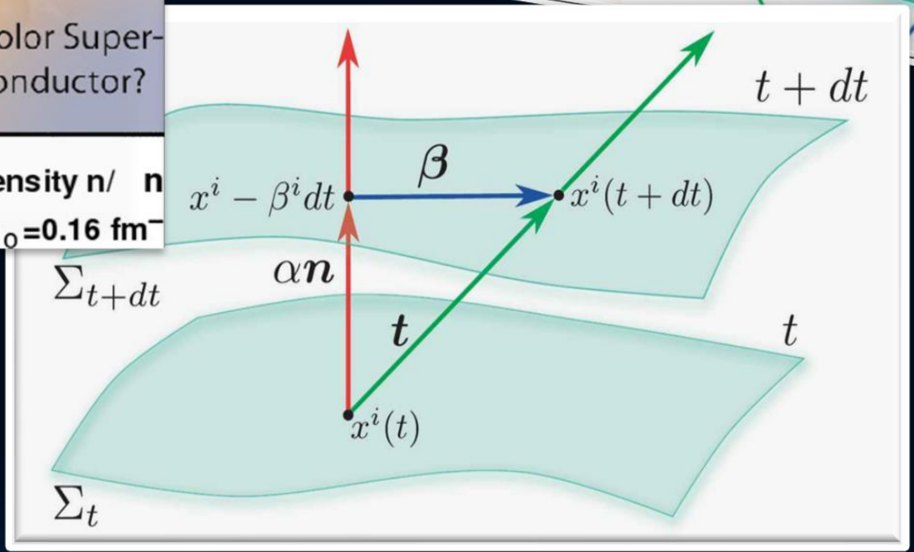
$R_{\mu\nu}$ … $= 0\,,$
… $= 0\,.$

(3+…

g_{μ} … $\beta_i \quad \gamma_{ij}$



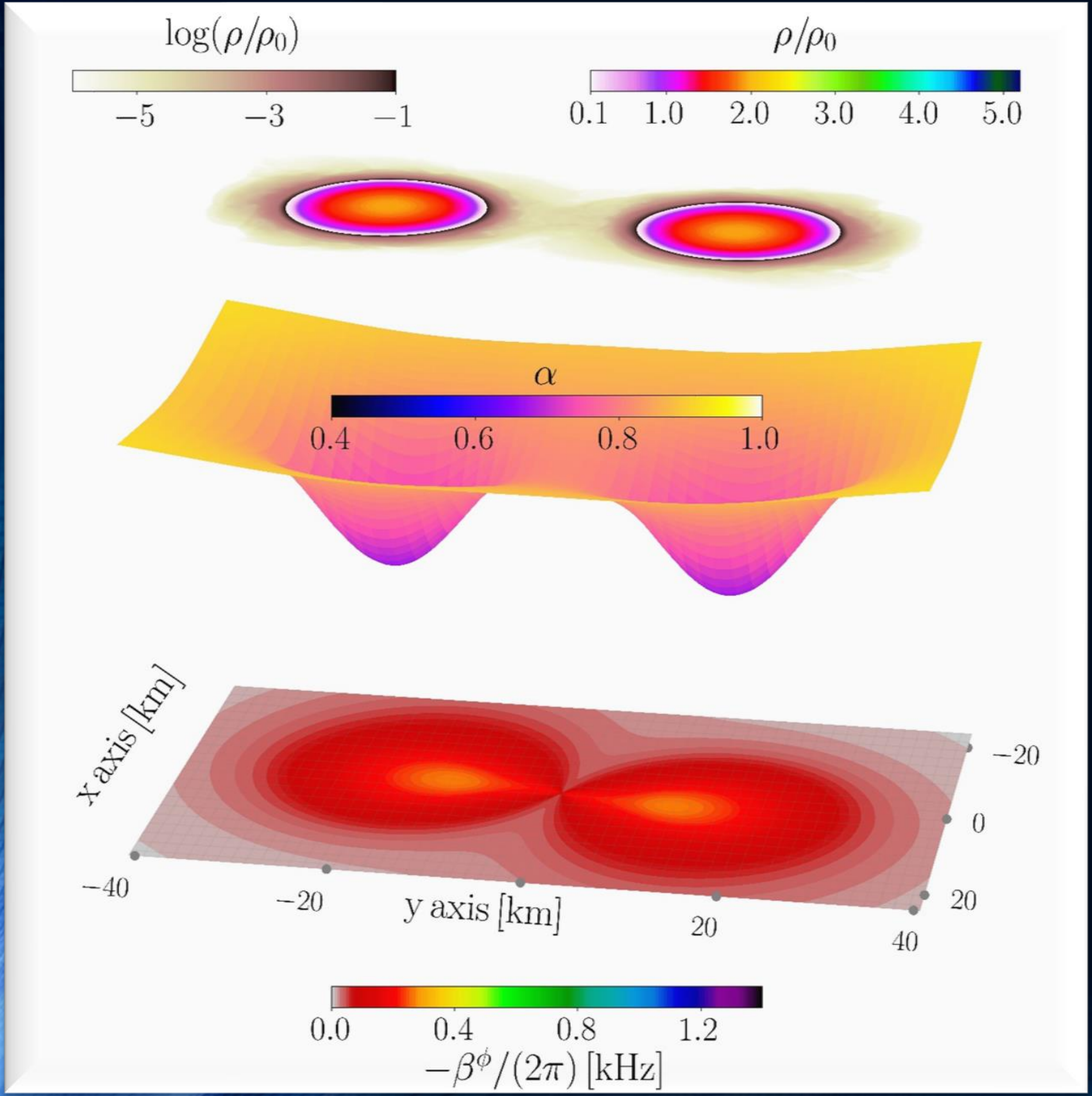


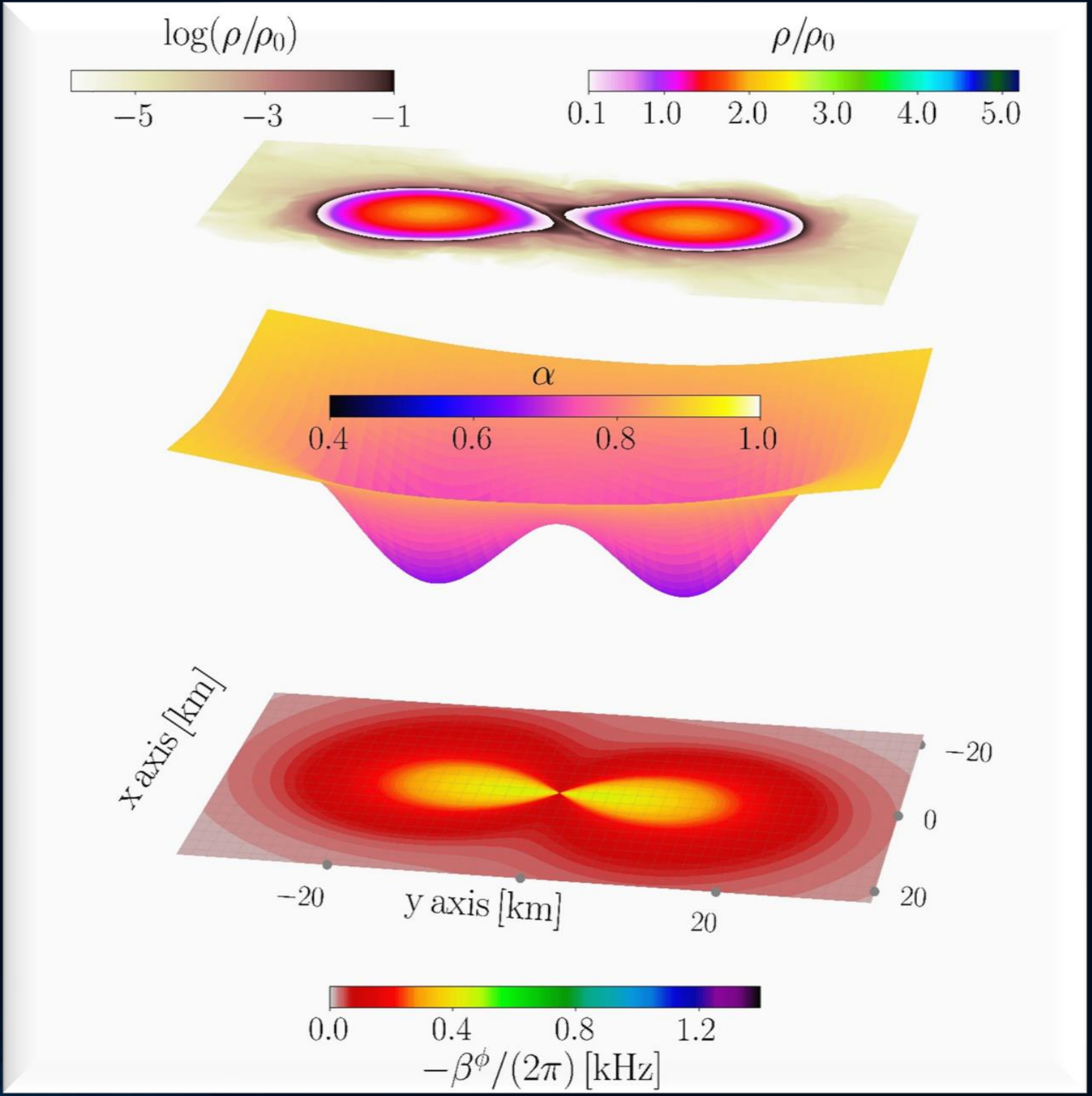


$d\tau^2 = \alpha^2(t, x^j)dt^2$ $\quad$ $x^i_{t+dt} = x^i_t - \beta^i(t, x^j)dt$

All figures and equations from: Luciano Rezzolla, Olindo Zanotti: Relativistic Hydrodynamics, Oxford Univ. Press, Oxford (2013)

The late inspiral phase (density, lapse and shift)

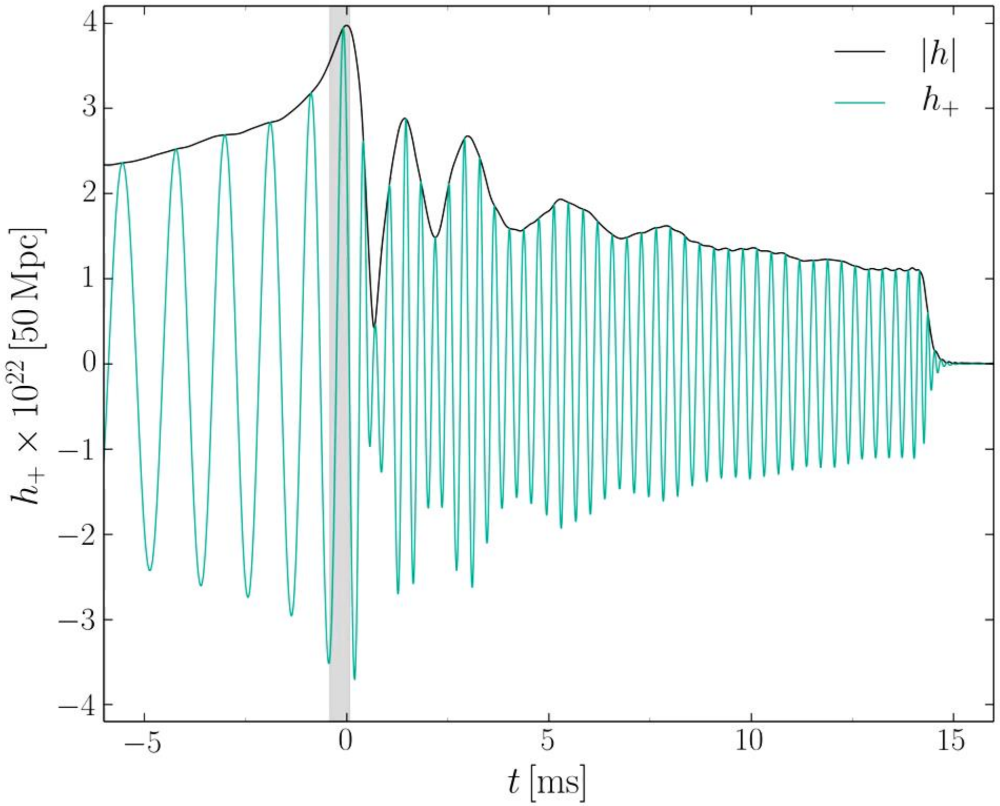




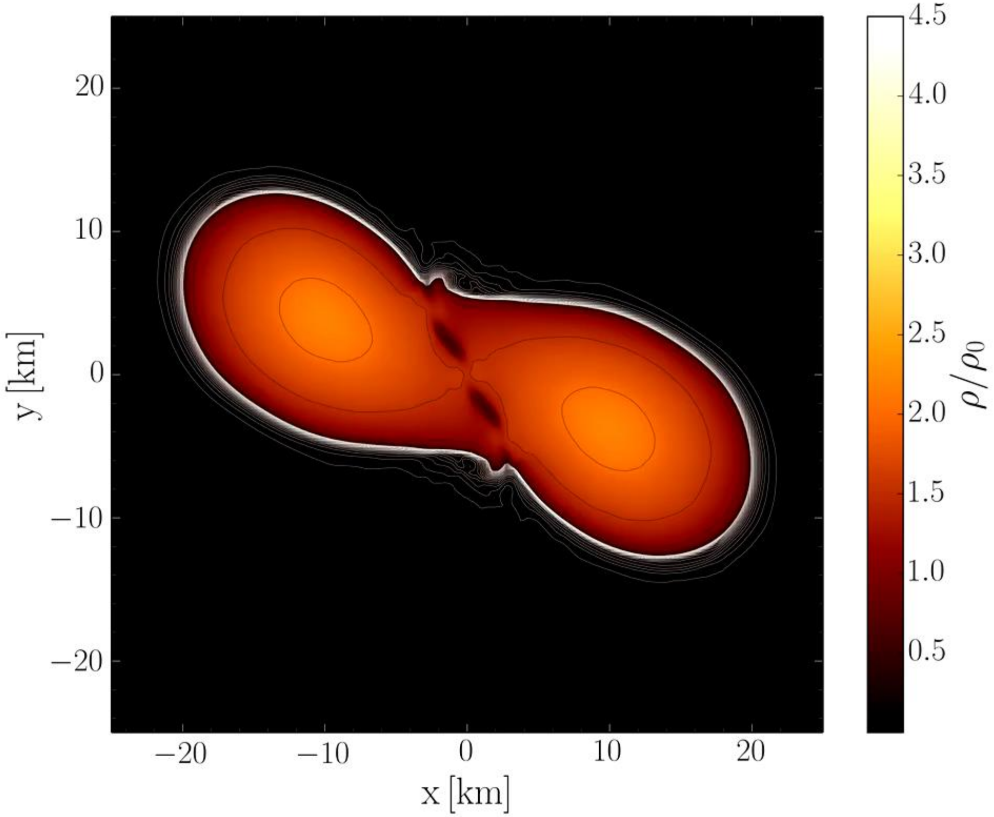
Gravitational Waves and Hypermassive Hybrid Stars

ALF2-EOS: Mixed phase region starts at $3\rho_0$ (see red curve), initial NS mass: 1.35 M_{solar}

Hanauske, et.al. PRD, 96(4), 043004 (2017)

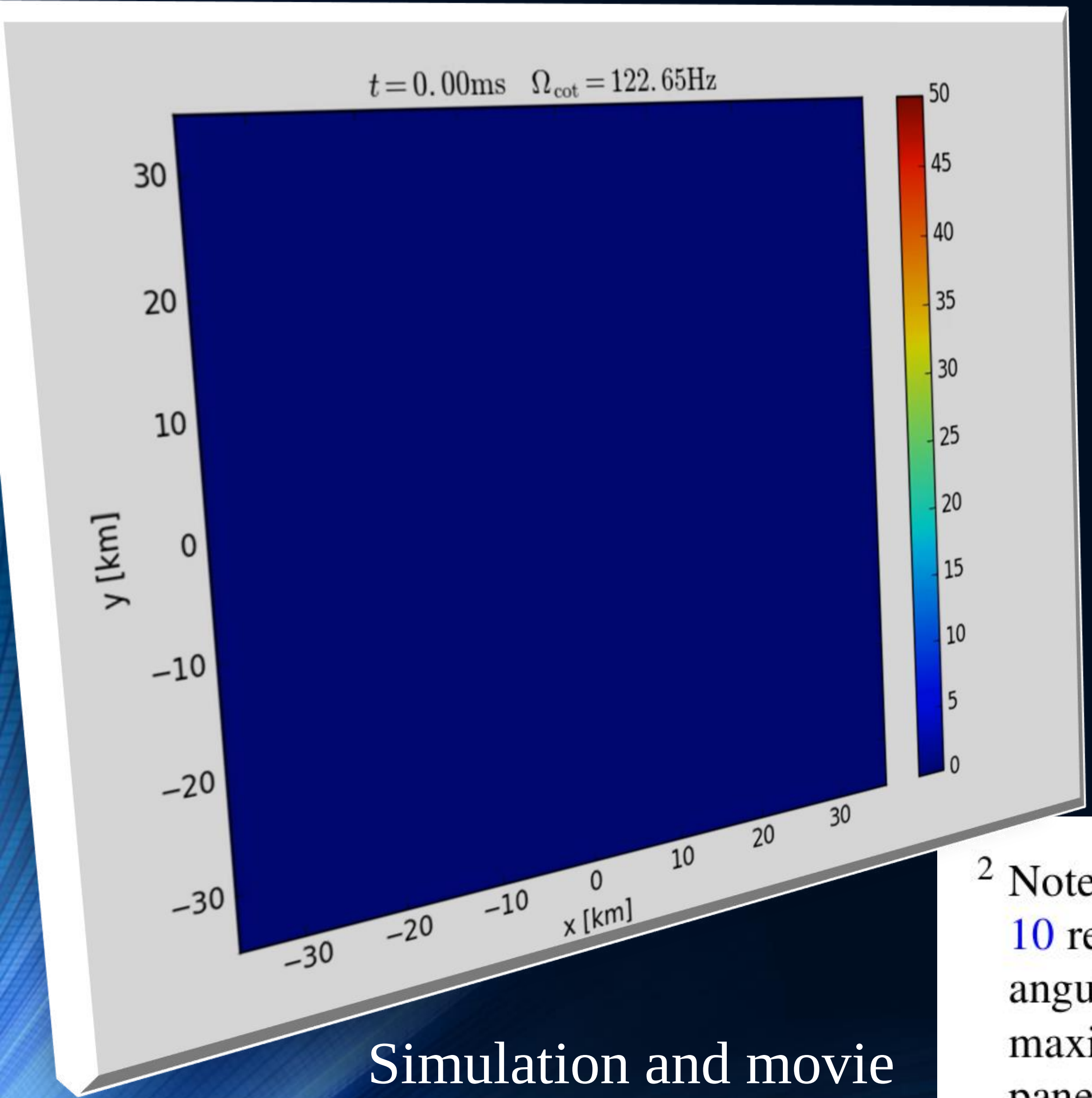


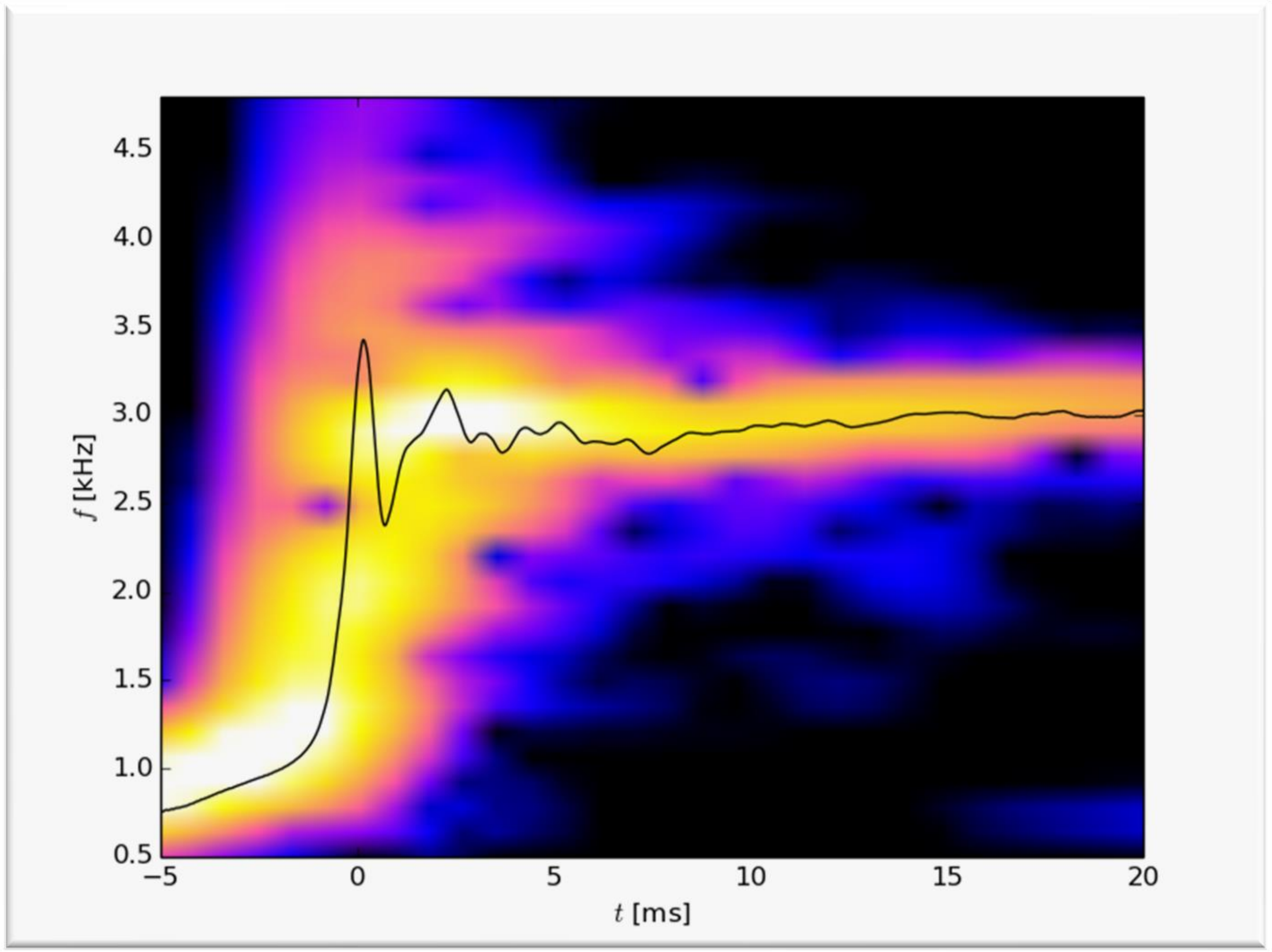
Gravitational wave amplitude
at a distance of 50 Mpc



Rest mass density distribution ρ(x,y)
in the equatorial plane
in units of the nuclear matter density ρ_0

The Co-Rotating Frame

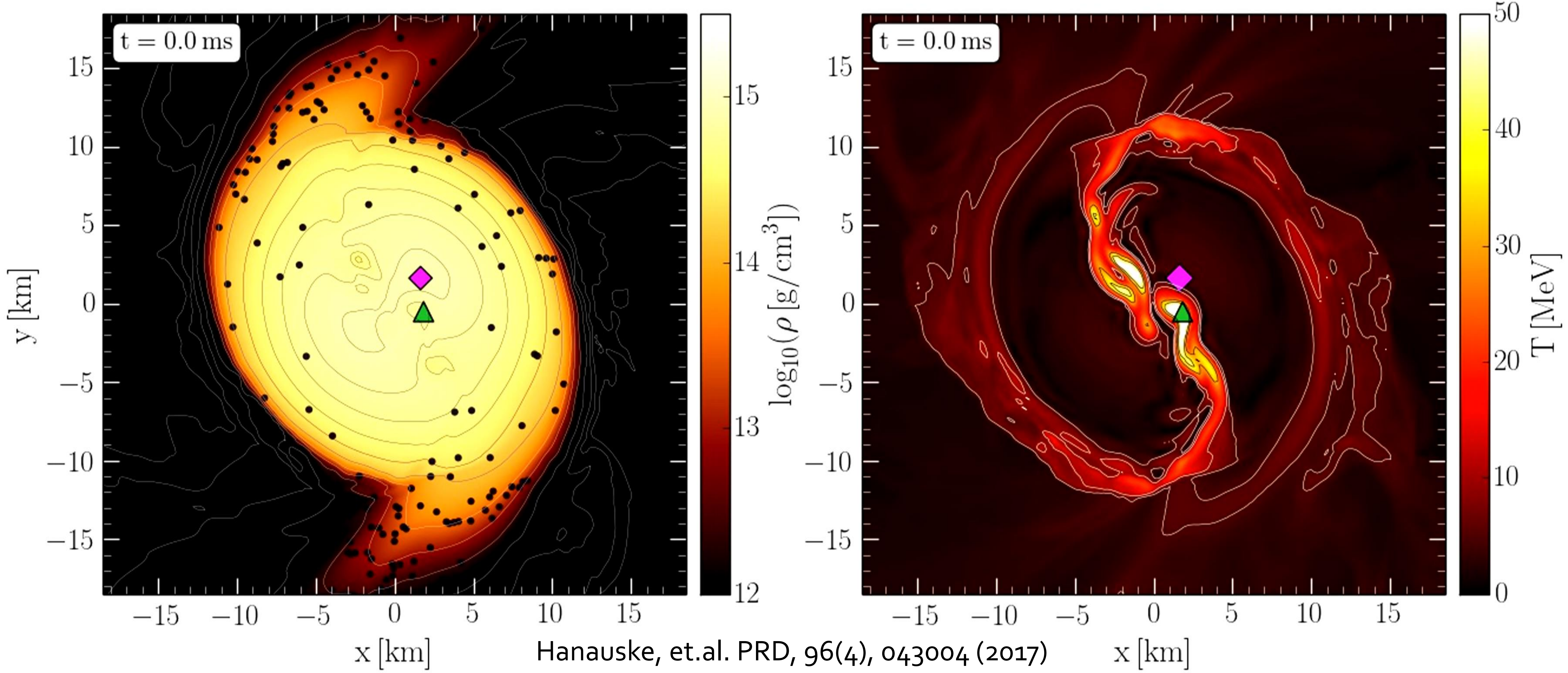




Simulation and movie
has been produced by Luke Bovard

[2] Note that the angular-velocity distribution in the lower central panel of Fig. 10 refers to the corotating frame and that this frame is rotating at half the angular frequency of the emitted gravitational waves, Ω_{GW}. Because the maximum of the angular velocity Ω_{max} is of the order of $\Omega_{GW}/2$ (cf. left panel of Fig. 12), the ring structure in this panel is approximately at zero angular velocity.

Density and Temperature Evolution inside the HMNS

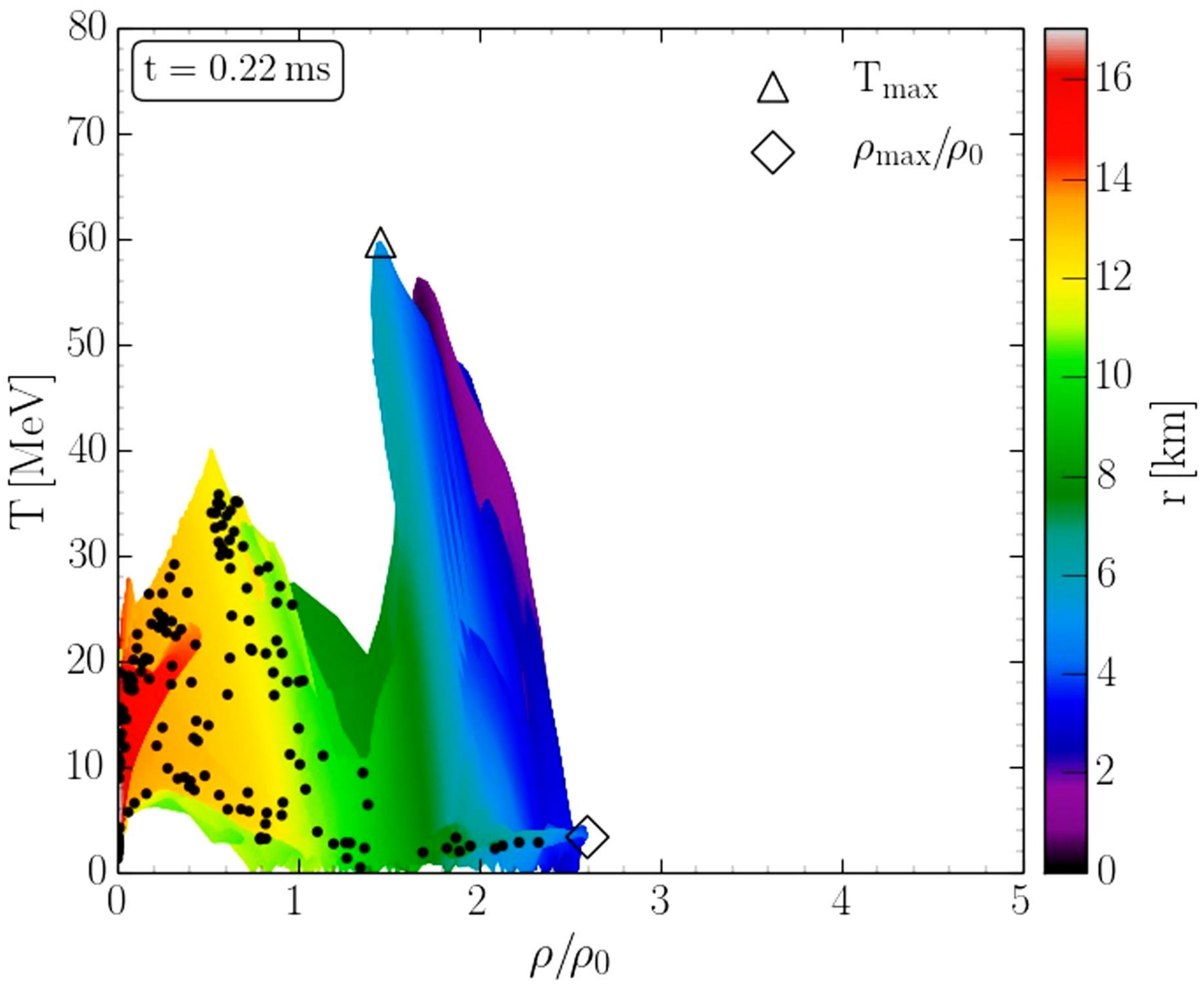


Hanauske, et.al. PRD, 96(4), 043004 (2017)

Rest mass density on the equatorial plane

Temperature on the equatorial plane

Binary Neutron Star Mergers in the QCD Phase Diagram



Evolution of hot and dense matter inside the inner area of a hypermassive neutron star simulated within the LS220 EOS with a total mass of $M_{total}=2.7\,M_\odot$ in the style of a (T- ρ) QCD phase diagram plot

The color-coding indicate the radial position r of the corresponding (T- ρ) fluid element measured from the origin of the simulation (x , y) = (0 , 0) on the equatorial plane at z = 0.

The open triangle marks the maximum value of the temperature while the open diamond indicates the maximum of the density.

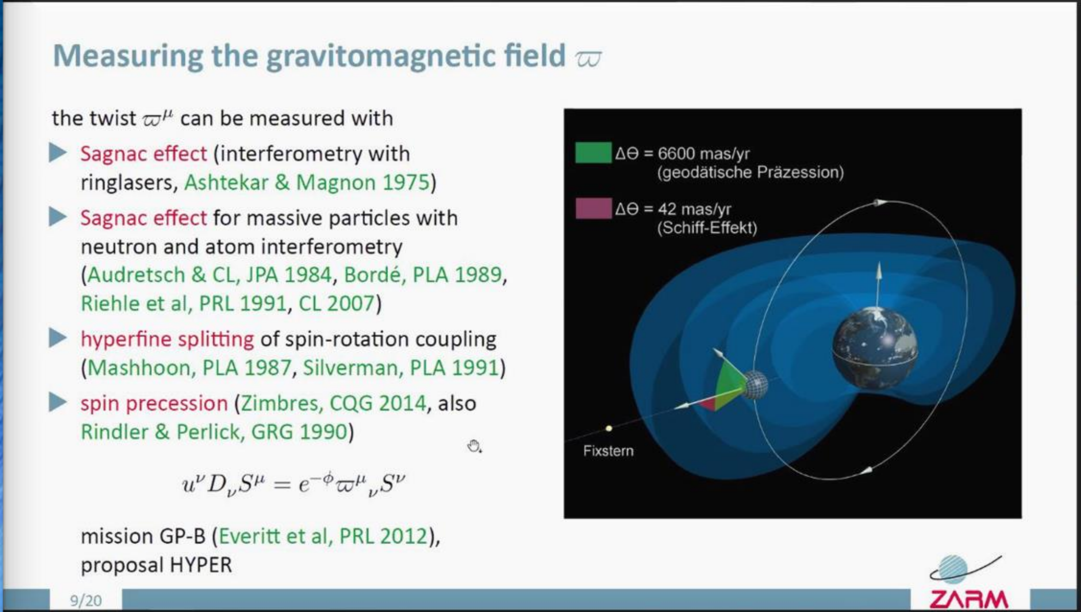
The Angular Velocity in the (3+1)-Split

The angular velocity Ω in the (3+1)-Split is a combination of the lapse function α , the ϕ-component of the shift vector β^ϕ and the 3-velocity v^ϕ of the fluid (spatial projection of the 4-velocity **u**):

$$\Omega(x,y,z,t) = \frac{u^\phi}{u^t} = \alpha\, v^\phi \;-\; \beta^\phi$$

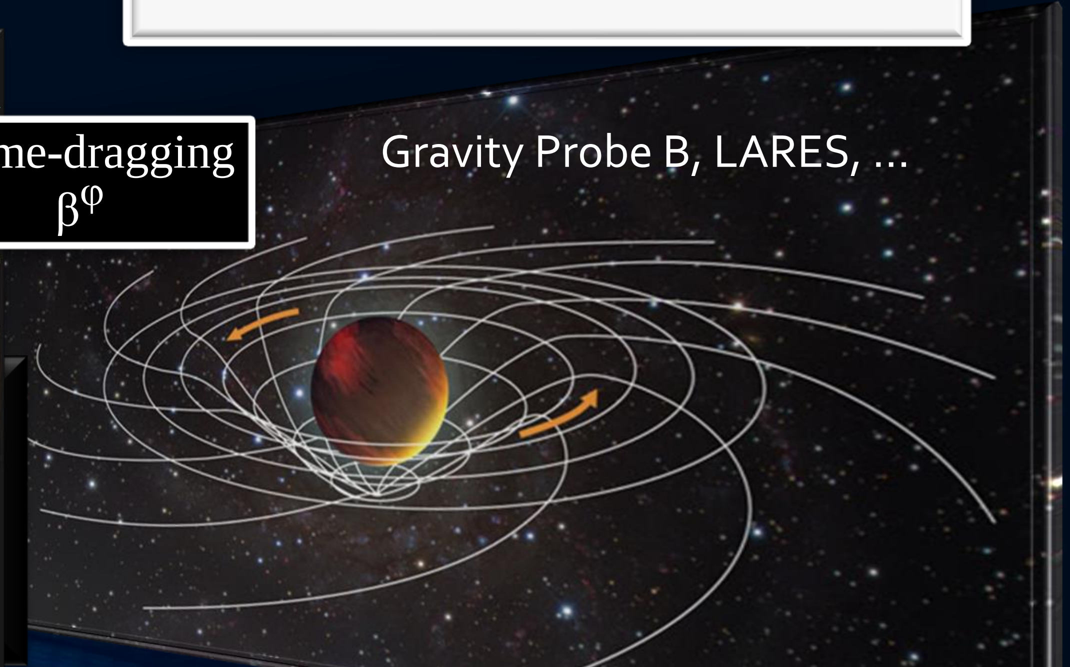
(3+1)-decomposition of spacetime:

$$g_{\mu\nu} = \begin{pmatrix} -\alpha^2 + \beta_i\beta^i & \beta_i \\ \beta_i & \gamma_{ij} \end{pmatrix}$$



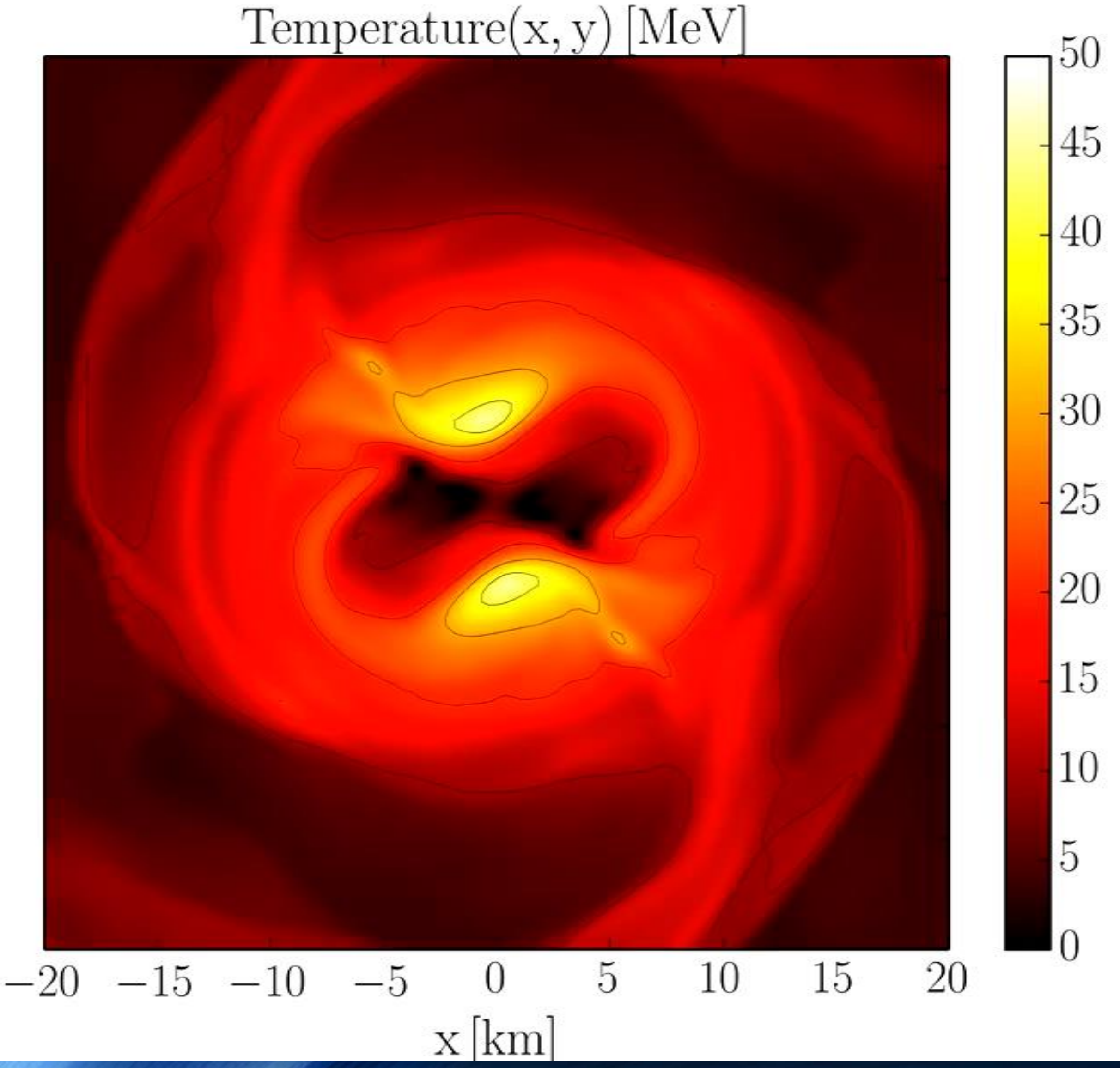
Frame-dragging β^φ

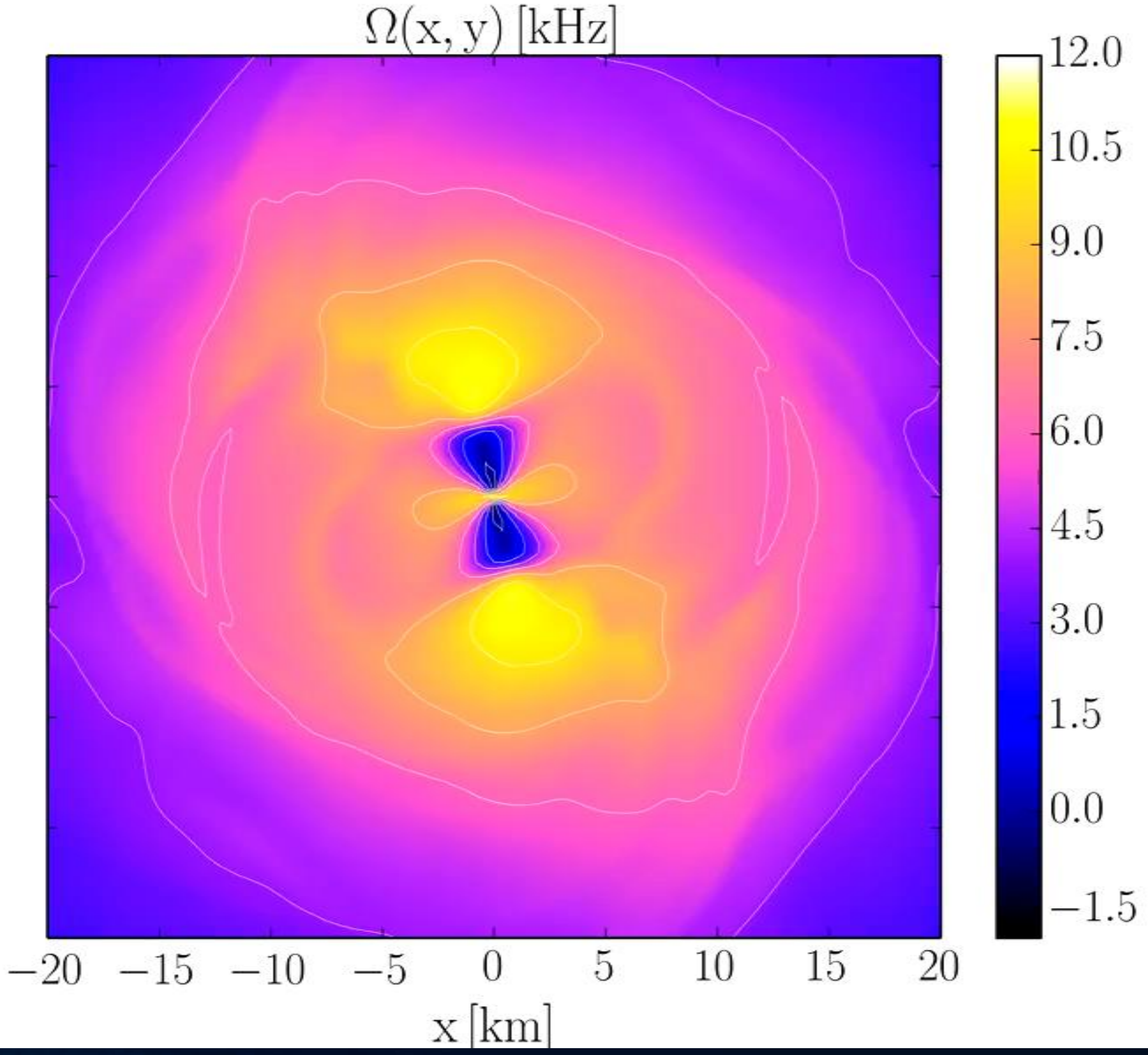
Today's talks by C.Lämmerzahl and J.Frauendiener



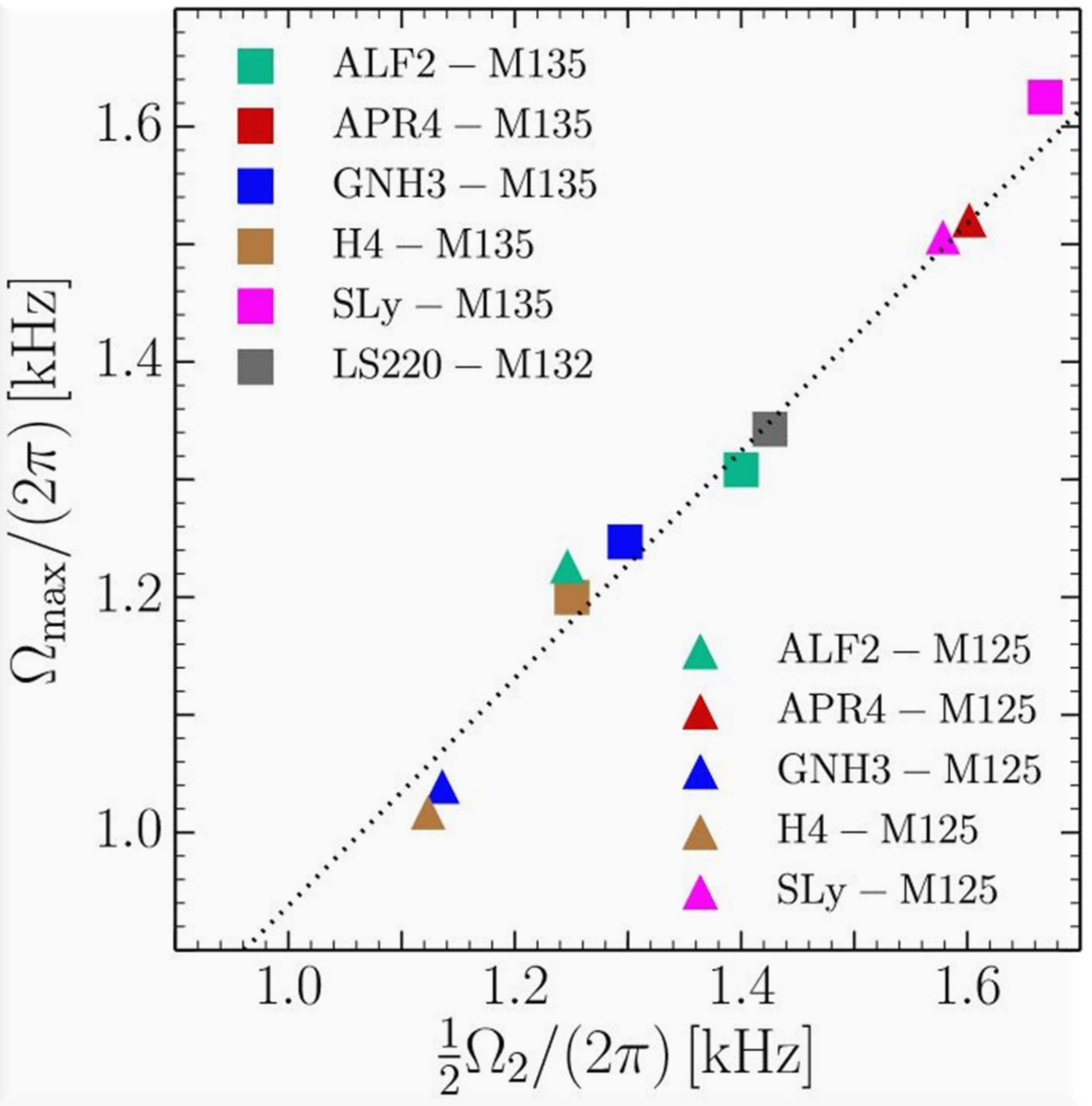
Temperature

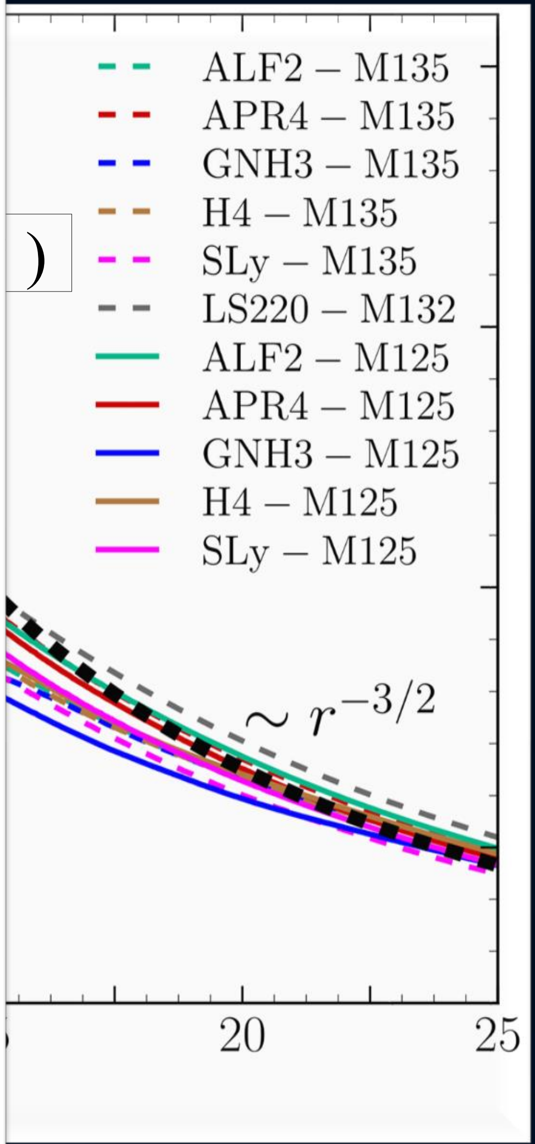
Angular Velocity





EOS: LS200 , Mass: 1.32 M_{solar} , simulation with Pi-symmetry files of the HMNSs





<u>Soft EoSs</u>:
Sly
APR4

<u>Stiff EoSs</u>:
GNH3
H4

S

Hanauske, et.al. PRD, 96(4), 043004 (2017)

lashed curves).

Can we detect the quark-gluon plasma with gravitational waves?

Yesterday's Talk

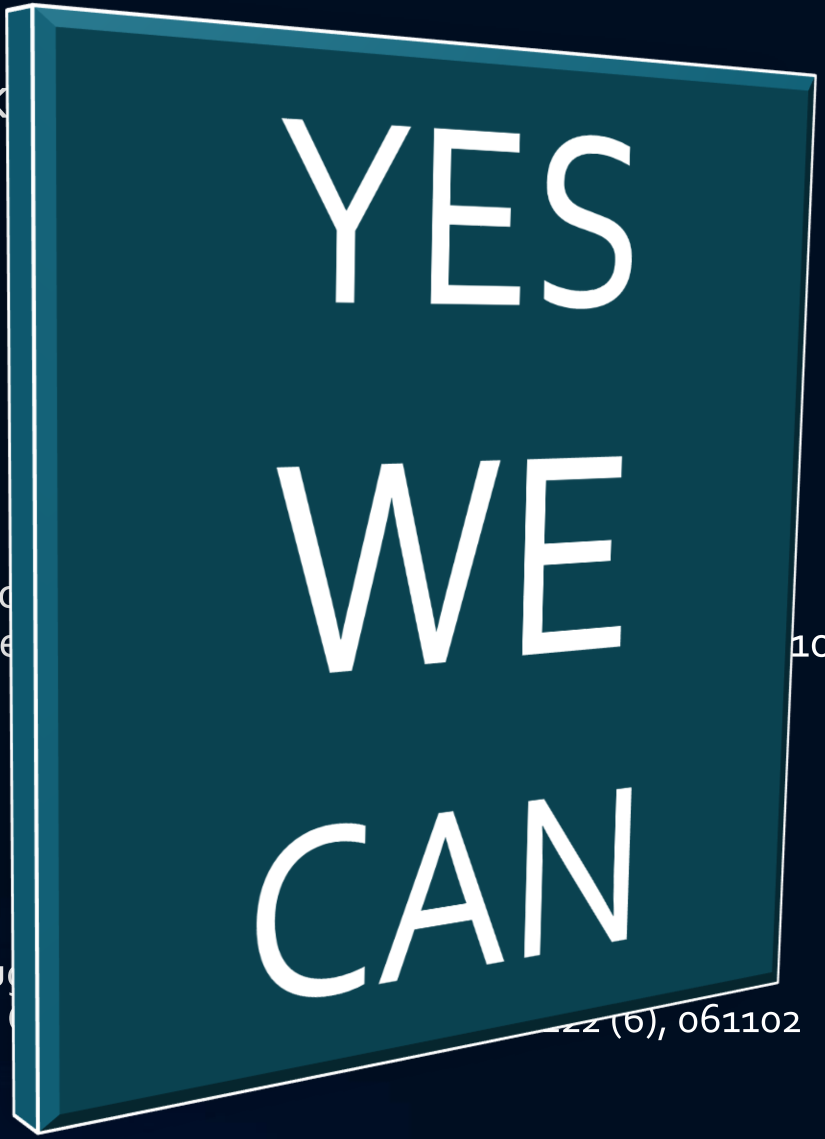
M.Hanauske

Gravitational-wave signatures of the hadron-quark phase transition in binary neutron star mergers

DPG division: Hadronic and Nuclear Physics

5.00 PM in HK 5.2

- Gravitational-wave signatures of the hadron-quark compact star mergers
  - *Signatures within the late inspiral phase (premerger signals)*
    - Constraining twin stars with GW170817; G Montana, L Tolós, M
      99 (10), 103009 (2019)
  - *Signatures within the post-merger phase evolution*
    - **Phase-transition triggered collapse scenario**
      Signatures of quark-hadron phase transitions in general-relativistic
      Papenfort, V Dexheimer, M Hanauske, S Schramm, H Stöcker, L. Re 101
      (2019)
    - **Delayed phase transition scenario**
      Postmerger Gravitational-Wave Signatures of Phase Transitions in
      Rezzolla; Physical Review Letters 124 (17), 171103 (2020)
    - **Prompt phase transition scenario**
      Identifying a first-order phase transition in neutron-star mergers throu
      Bastian, DB Blaschke, K Chatziioannou, JA Clark, JA Clark, T Fischer, M 22 (6), 061102
      (2019)



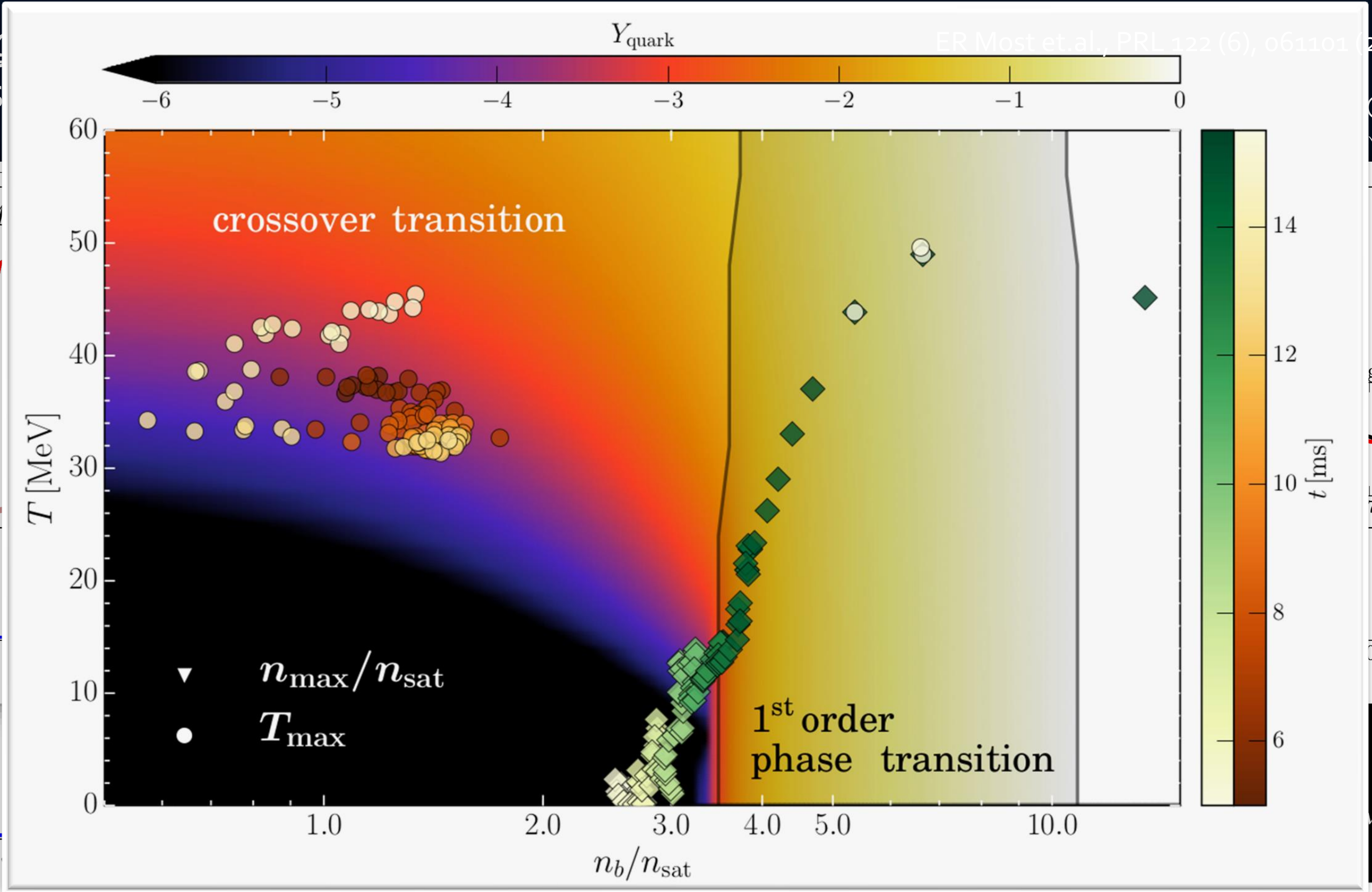
Sig

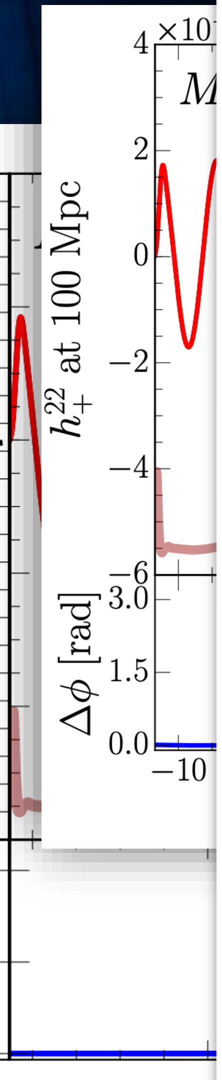
Phas

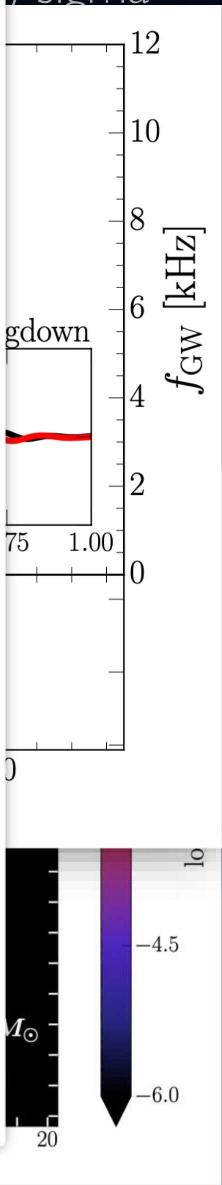
ER Most et al., PRL 122 (6), 061101 (2019)

CMF)

) sigma





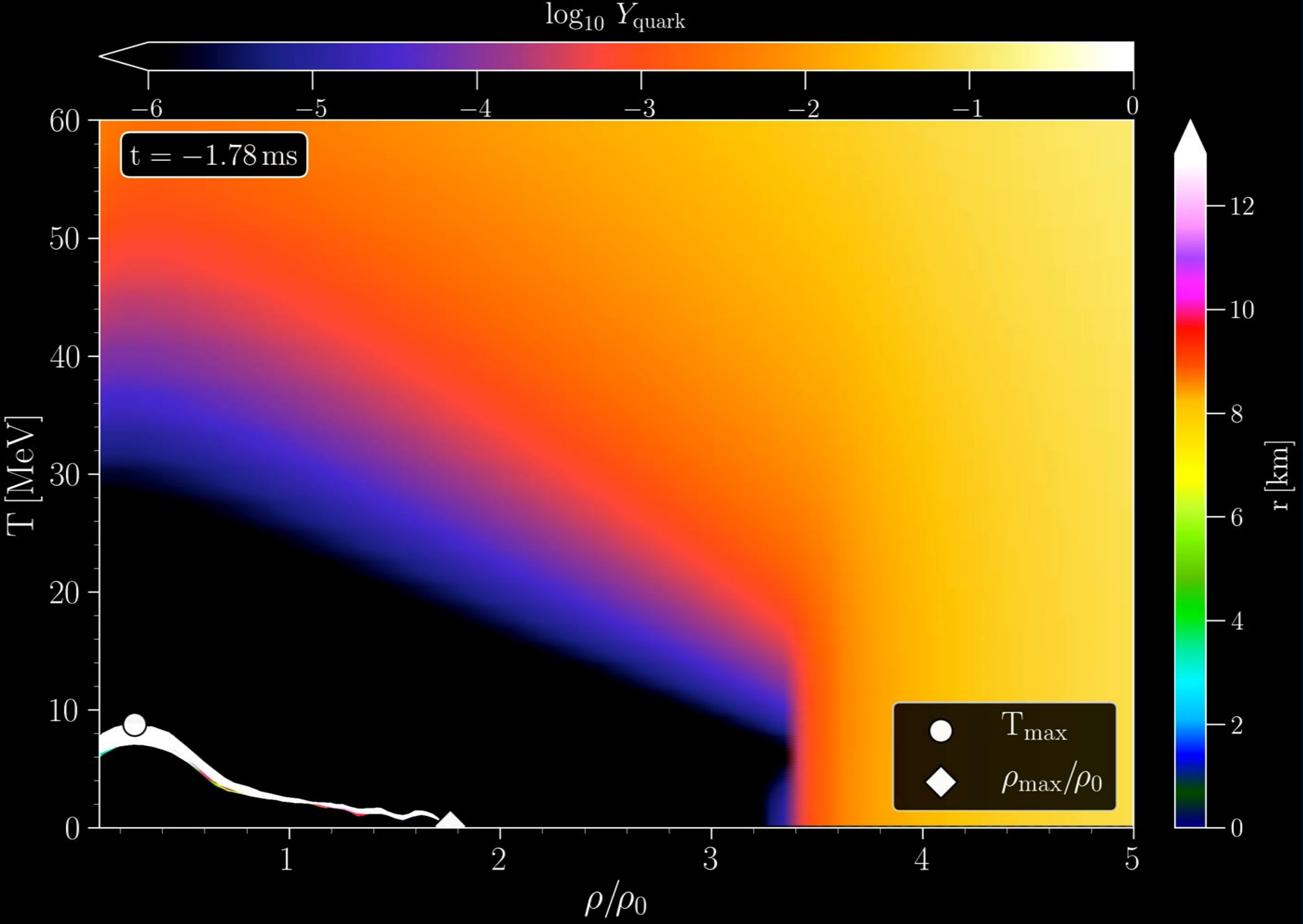


Phase-transition triggered collapse scenario

Signatures of quark-hadron phase transitions in general-relativistic neutron-star mergers

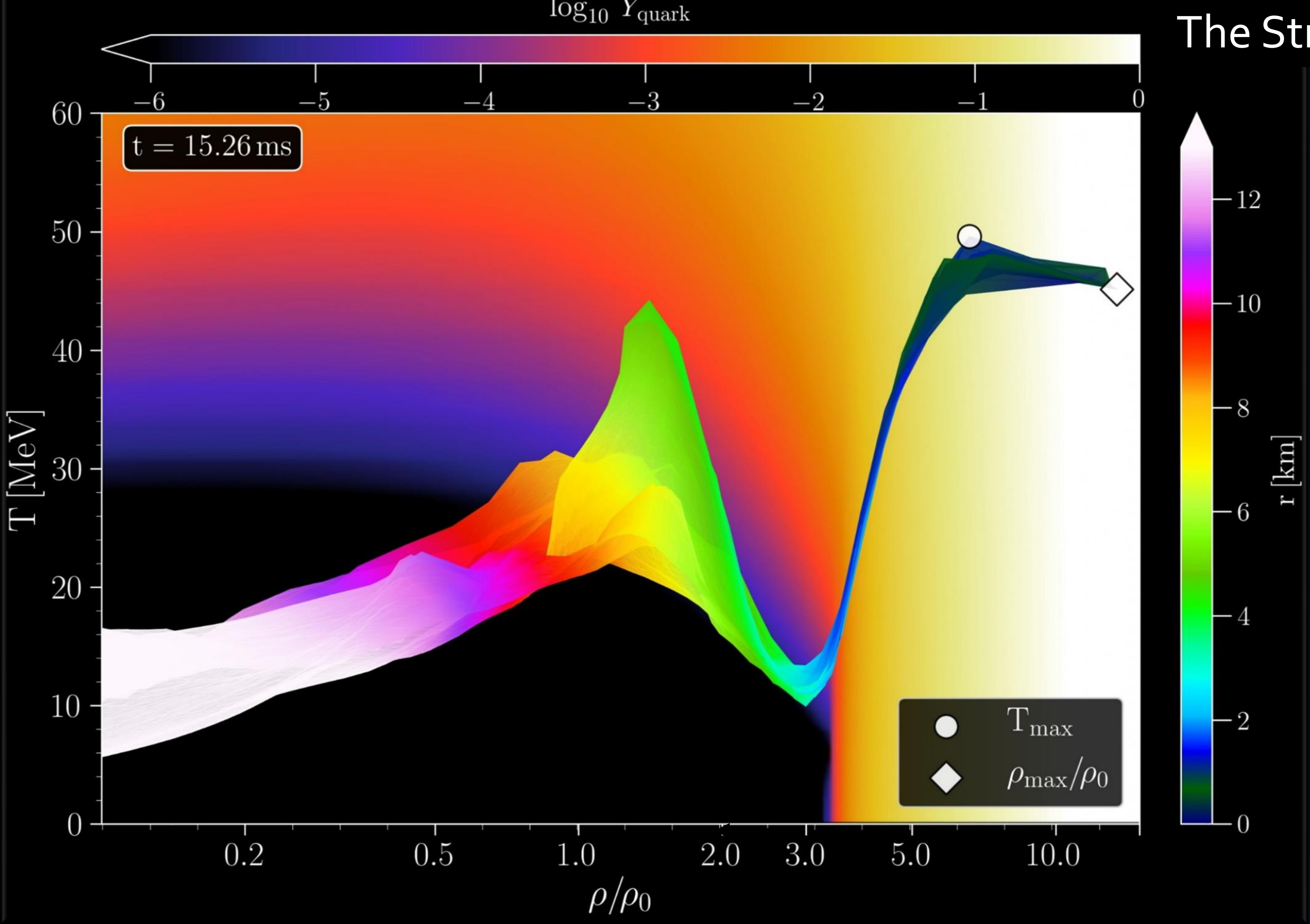
ER Most, LJ Papenfort, V Dexheimer, M Hanauske, S Schramm, H Stöcker and L. Rezzolla

Physical review letters 122 (6), 061101 (2019)

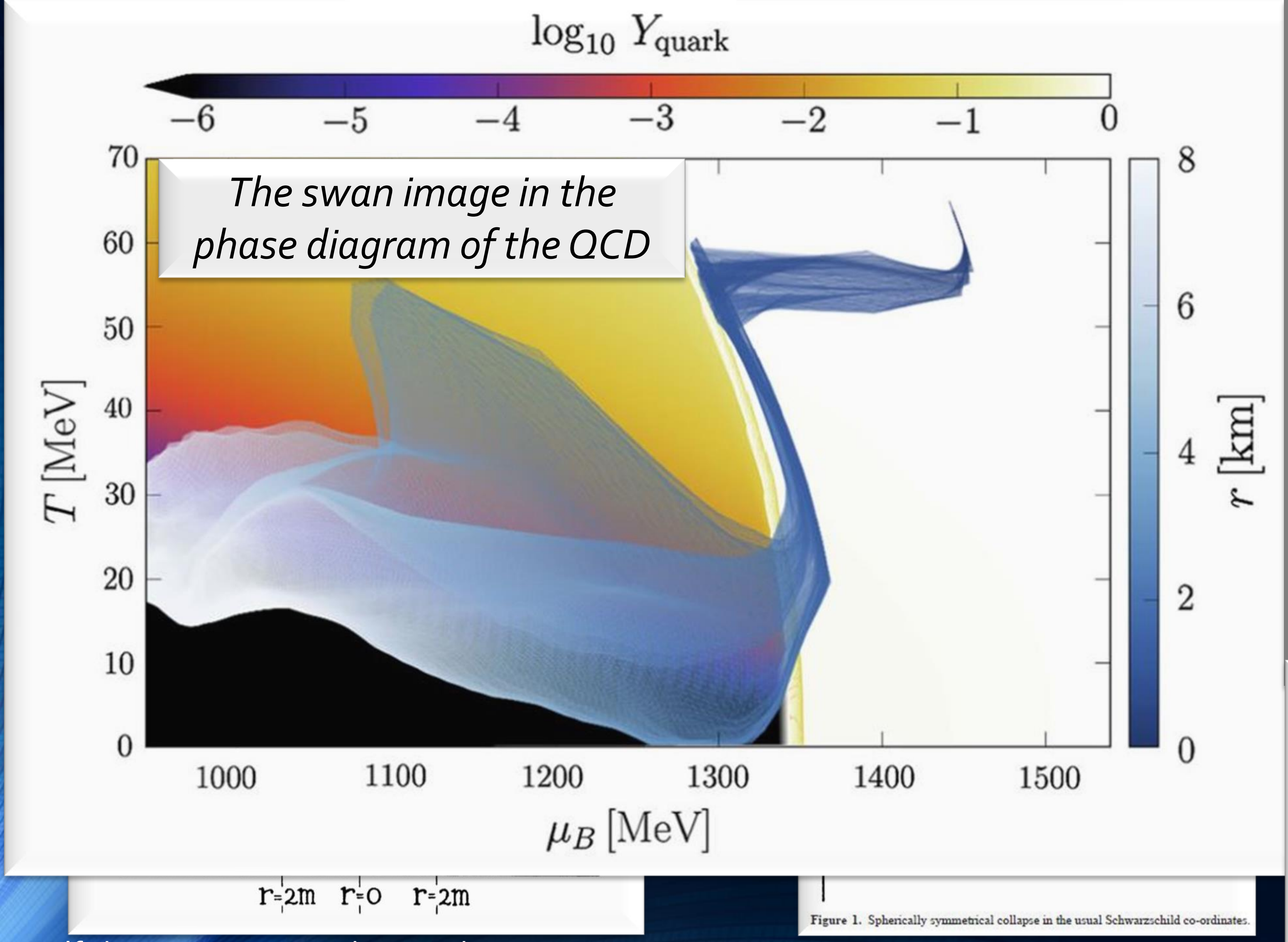


Density-Temperature-Composition dependent EOS within the CMFQ model.

The Strange Bird Plot



While the quarks in the bird's head have already rescued themselves from their confinement cage, his body still largely consists of hadronic particles. It is precisely at this point in time that the apparent horizon is formed around the dense and hot head of the strange bird and the free strange quark matter is macroscopically confined by the formation of the black hole.



E.Most, J. Papenfort, V.Dexheimer, M.Hanauske, H.Stöcker and L.Rezzolla, *On the deconfinement phase transition in neutron-star mergers* The European Physical Journal A 56 (2), 1-11 (2020)

A.Motornenko, M.Hanauske , L.Weih, J.Steinheimer and H.Stöcker, *MAGIC: Matter in Astrophysics, Gravitational Waves, and Ion Collisions. 原子核物理评论*, 37(3), 272-282 (2020)

The last picture what an outside observer sees is the frozen picture of a dying swan

Self-drawn space-time diagram by R.Penrose (1965)

R.Penrose in Rivista del Nuovo Ci

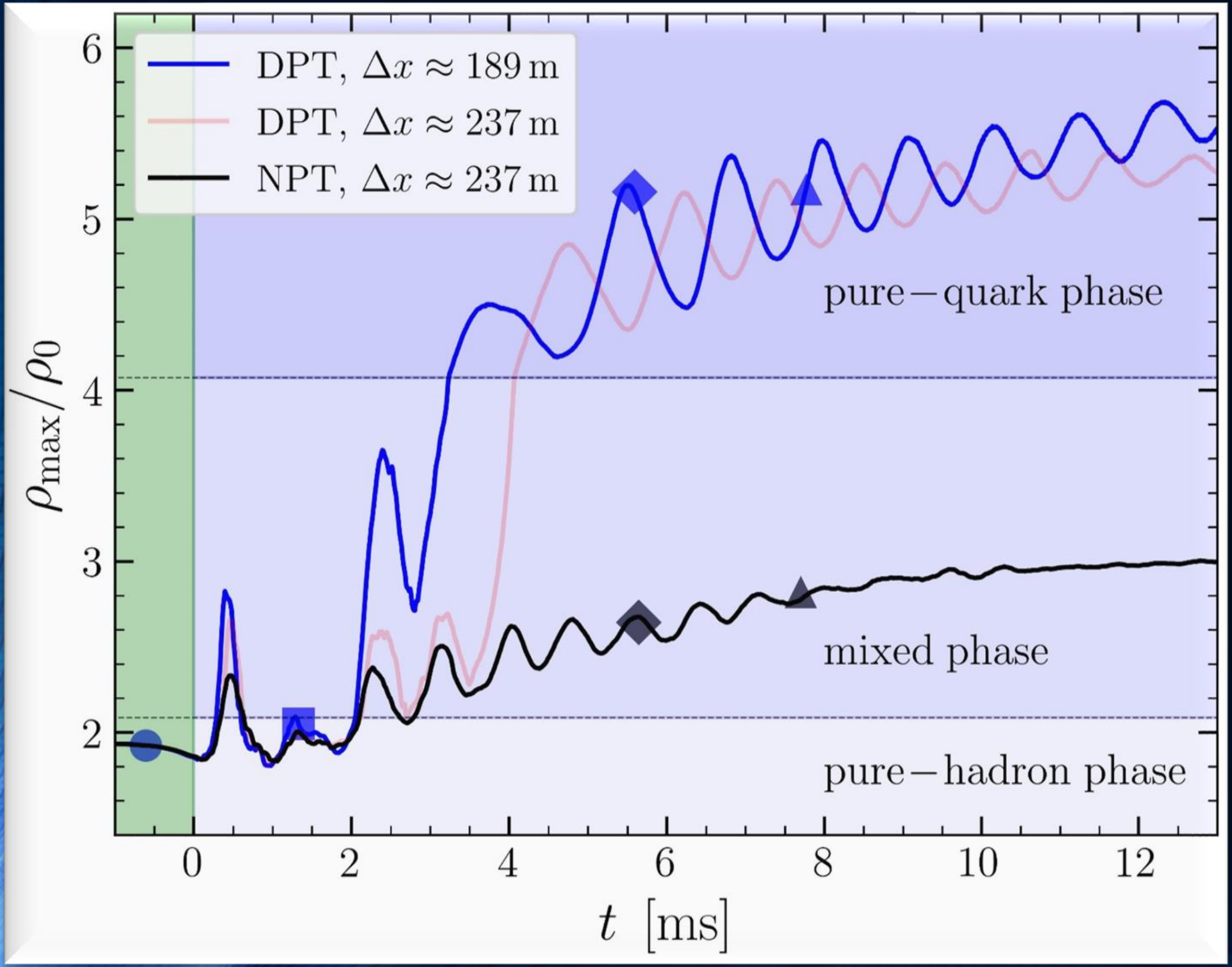
Can we detect the quark-gluon plasma with gravitational waves?

- Gravitational-wave signatures of the hadron-quark phase transition in binary compact star mergers
  - *Signatures within the late inspiral phase (premerger signals)*
    - Constraining twin stars with GW170817; G Montana, L Tolós, M Hanauske, L Rezzolla; Physical Review D 99 (10), 103009 (2019)
  - *Signatures within the post-merger phase evolution*
    - **Phase-transition triggered collapse scenario**
      Signatures of quark-hadron phase transitions in general-relativistic neutron-star mergers; ER Most, LJ Papenfort, V Dexheimer, M Hanauske, S Schramm, H Stöcker, L. Rezzolla; Physical review letters 122 (6), 061101 (2019)
    - **Delayed phase transition scenario**
      Postmerger Gravitational-Wave Signatures of Phase Transitions in Binary Mergers; LR Weih, M Hanauske, L Rezzolla; Physical Review Letters 124 (17), 171103 (2020)
    - **Prompt phase transition scenario**
      Identifying a first-order phase transition in neutron-star mergers through gravitational waves; A Bauswein, NUF Bastian, DB Blaschke, K Chatziioannou, JA Clark, JA Clark, T Fischer, M Oertel; Physical review letters 122 (6), 061102 (2019)

Signatures within the post-merger phase evolution

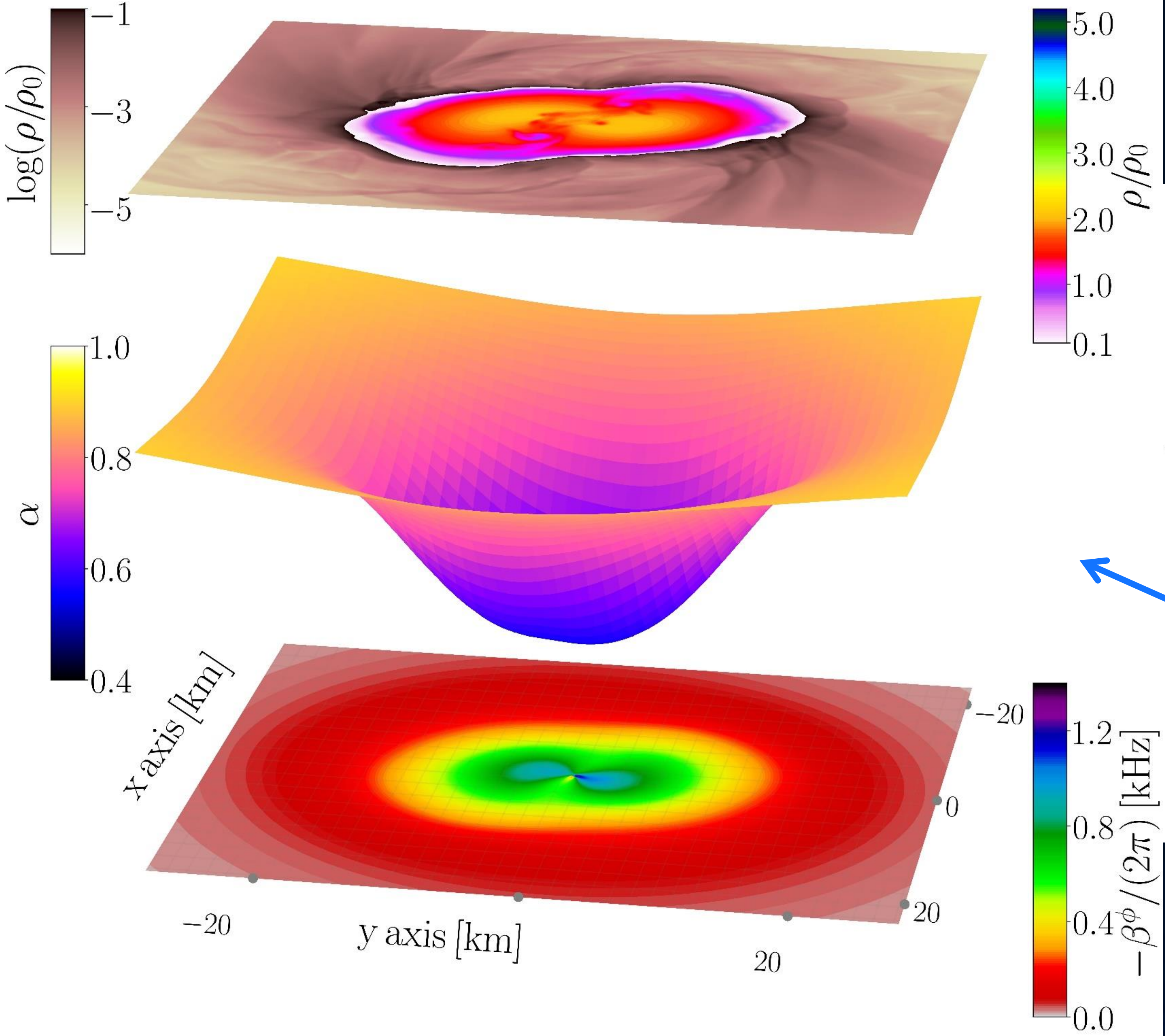
Delayed phase transition scenario

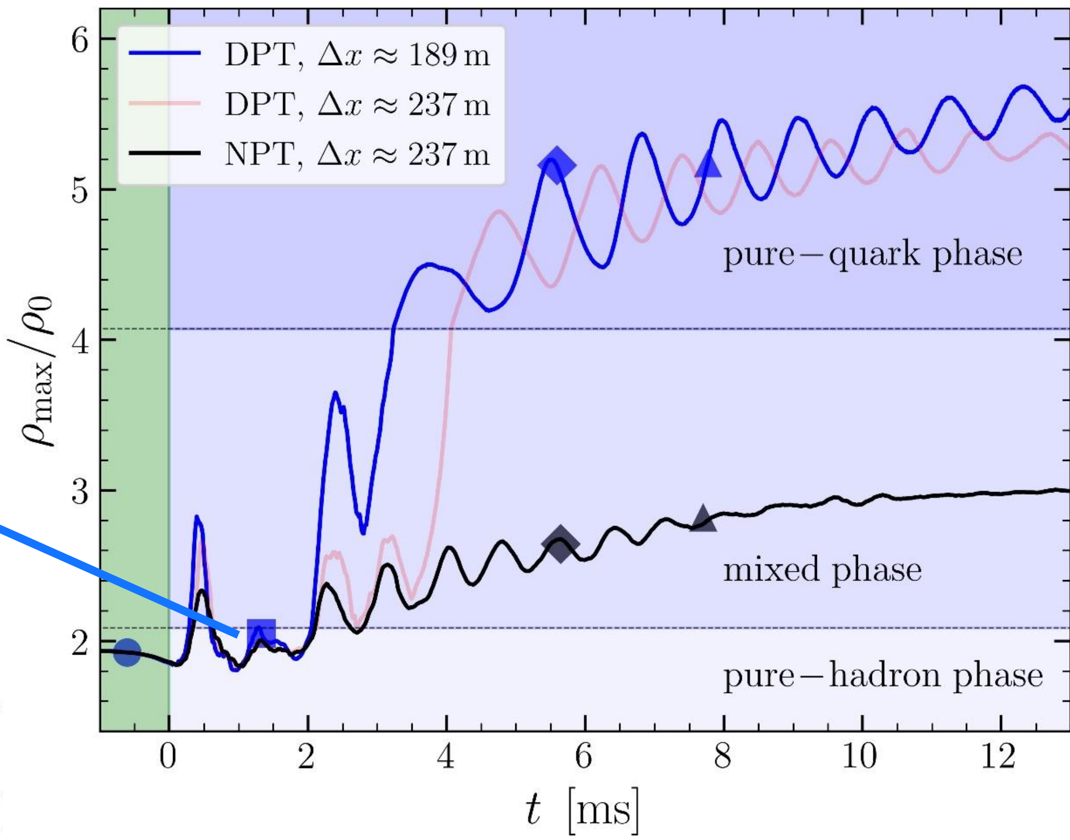
Postmerger Gravitational-Wave Signatures of Phase Transitions in Binary Mergers; LR Weih, M Hanauske, L Rezzolla; Physical Review Letters 124 (17), 171103 (2020)



Maximum value of the rest-mass density vs time for three binary neutron star simulations. Black curve without a phase transition (NPT) and blue/red with a Gibbs-like hadron-quark phase transition (DPT: standard/low resolution). Blue-shaded regions mark the different phases of the EOS (mixed phase and pure-quark phase).

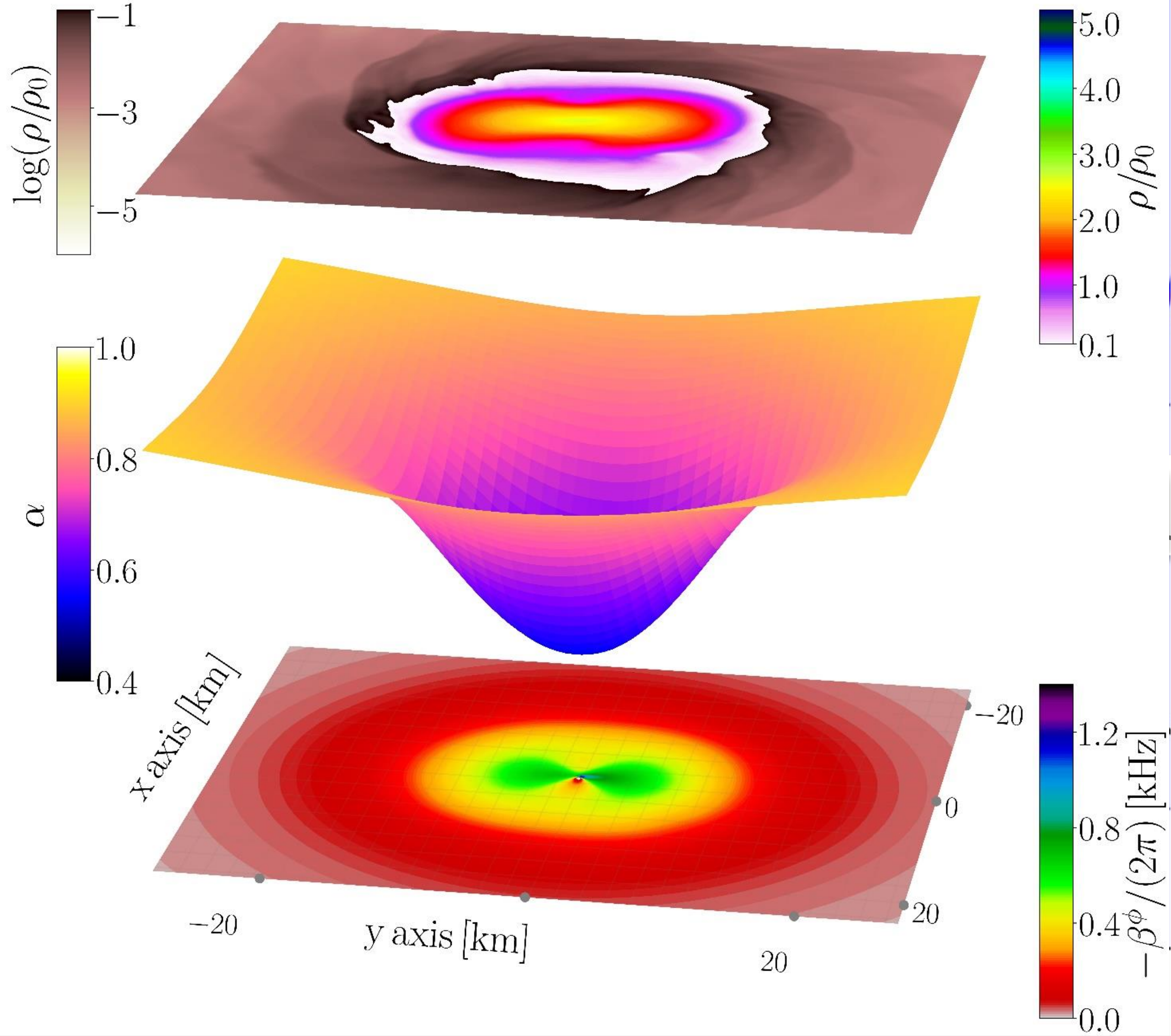
M. Hanauske, L. Weih, H. Stöcker, L. Rezzolla
Metastable hypermassive hybrid stars as neutron-star merger remnants
The European Physical Journal Special Topics: 1-8 (2021)



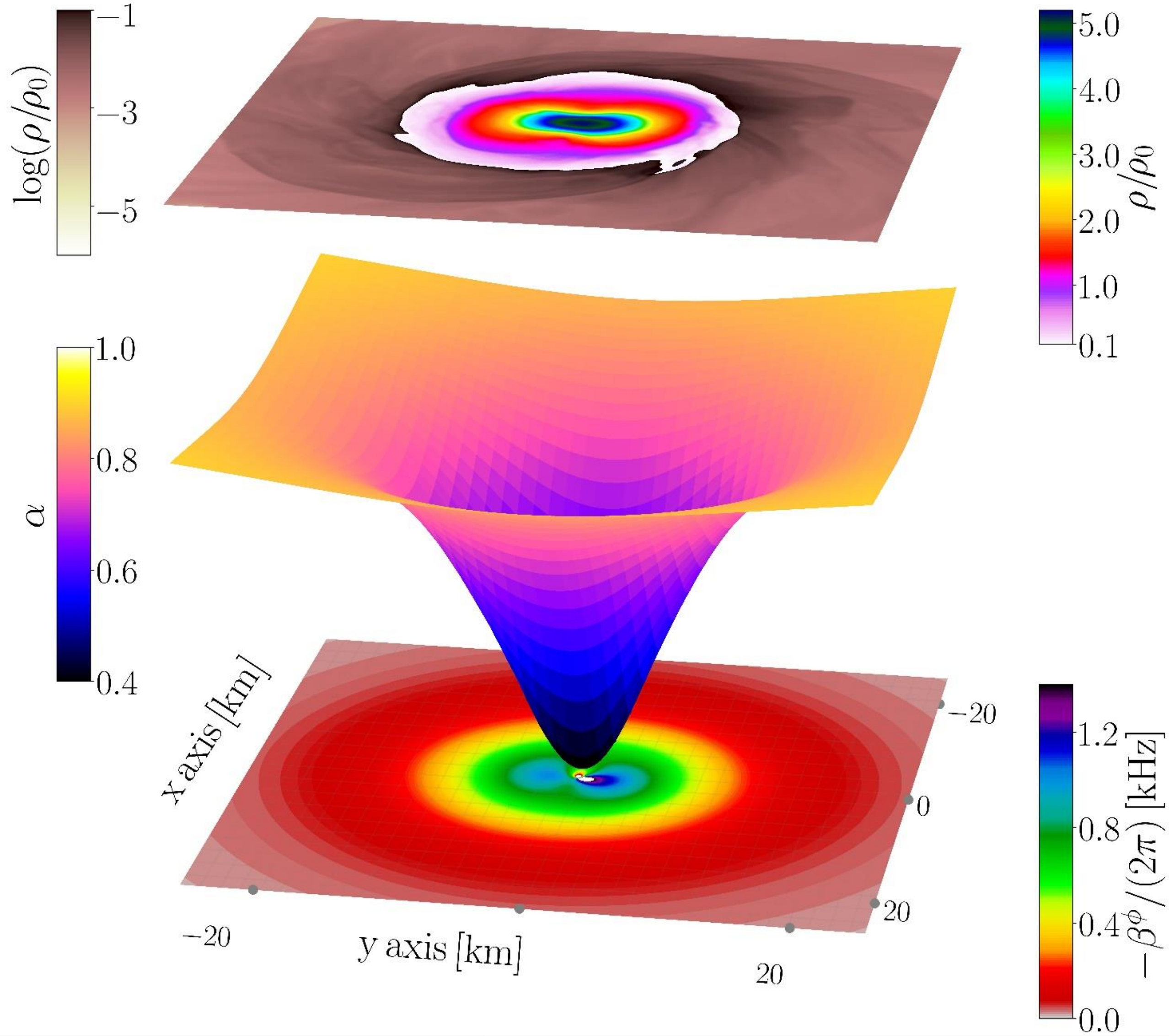


Matthias Hanauske and Lukas Weih
Neutron star collisions and gravitational waves
Astronomische Nachrichten (2021)

Without Phase Transition

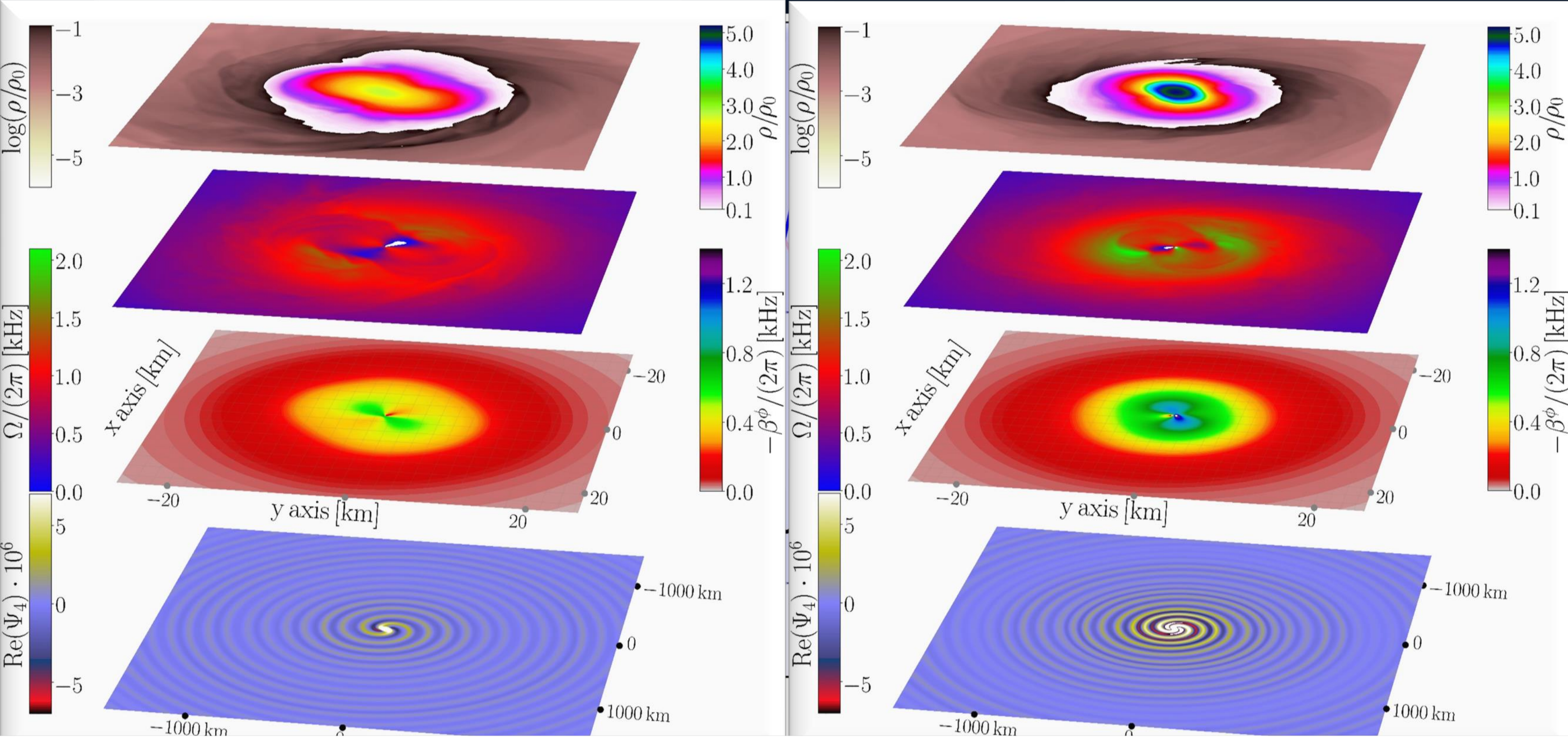


With Phase Transition

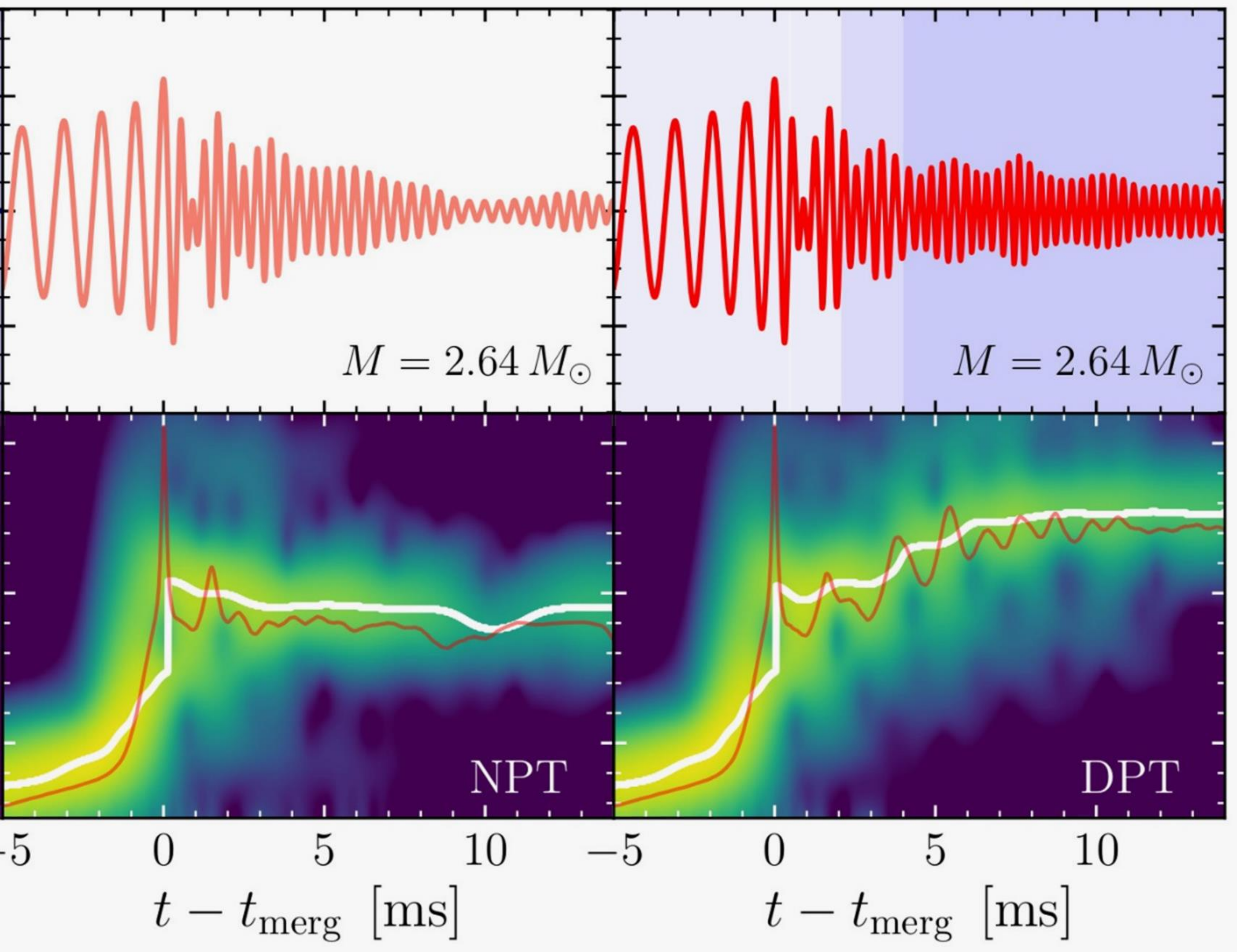


Matthias Hanauske and Lukas Weih. "Neutron star collisions and gravitational waves." *Astronomische Nachrichten* (2021)

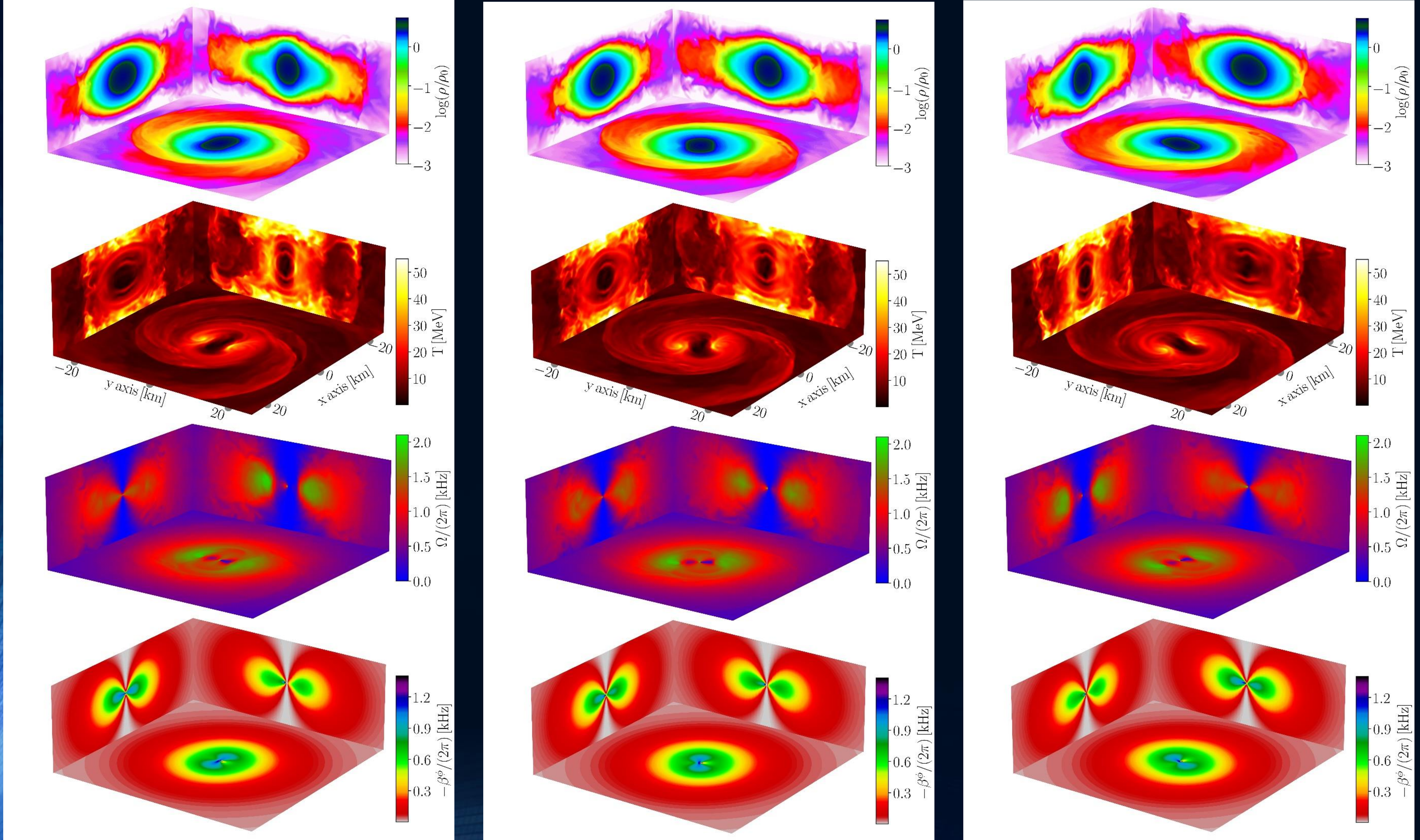
Without Phase Transition   With Phase Transition



Matthias Hanauske and Lukas Weih. "Neutron star collisions and gravitational waves." *Astronomische Nachrichten* (2021)



Strain h+ (top) and its spectrogram (bottom) for the binary neutron star simulation of the delayed phase transition scenario. In the top panel the different shadings mark the times when the HMHS core enters the mixed and pure quark phases. In the bottom panels, the white lines trace the maximum of the spectrograms, while the red lines show the instantaneous gravitational-wave frequency.



log(ρ/ρ0)
0
−1
−2
−3
T [MeV]
10
20
30
40
50
−20
y axis [km]
20
0
x axis [km]
Ω/(2π) [kHz]
0.0
0.5
1.0
1.5
2.0
−β^φ/(2π) [kHz]
0.3
0.6
0.9
1.2

- Additional Slides