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SYstèmes de Référence Temps-Espace

# Magnetic interactions in galactic binary dynamics:

## gravitational wave signature and implications for LISA observations

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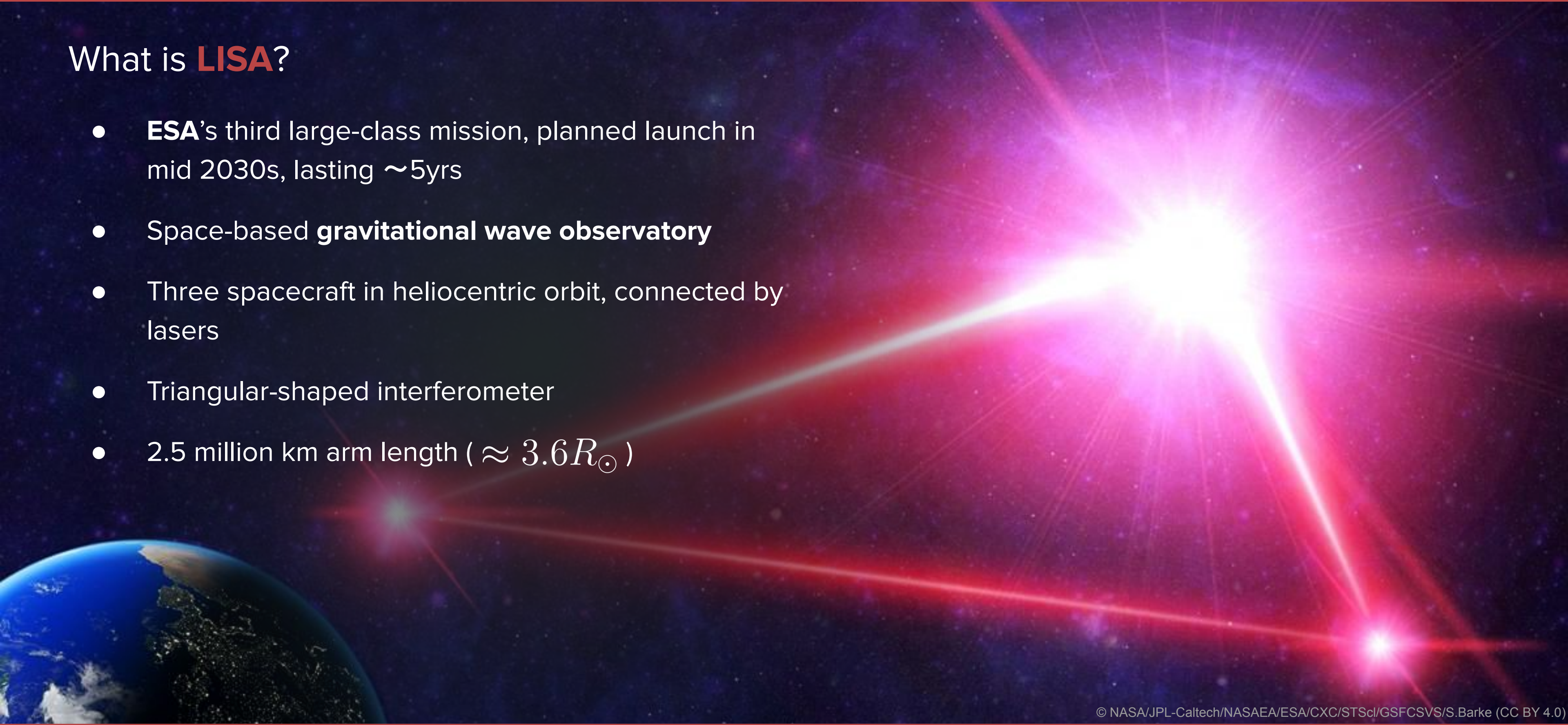
# Laser Interferometer Space Antenna

## What is LISA?

- **ESA**'s third large-class mission, planned launch in mid 2030s, lasting ∼5yrs
- Space-based **gravitational wave observatory**
- Three spacecraft in heliocentric orbit, connected by lasers
- Triangular-shaped interferometer
- 2.5 million km arm length ( $\approx 3.6 R_\odot$ )



# LISA: main sources

- Supermassive BH binaries
- Extreme Mass-Ratio Inspirals
- Inspiraling stellar BH binaries
- Primordial GWs
- Galactic binaries
(20k individual detections)
- etc

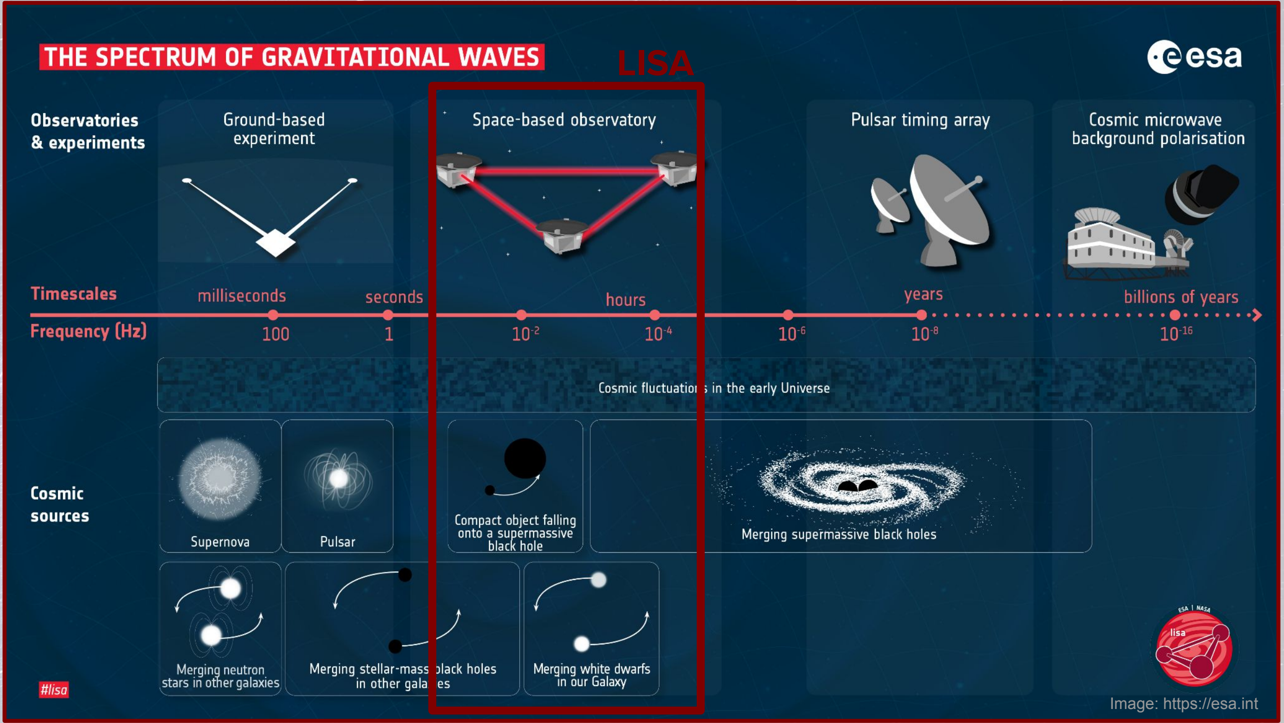



Image: https://esa.int

# LISA: main sources

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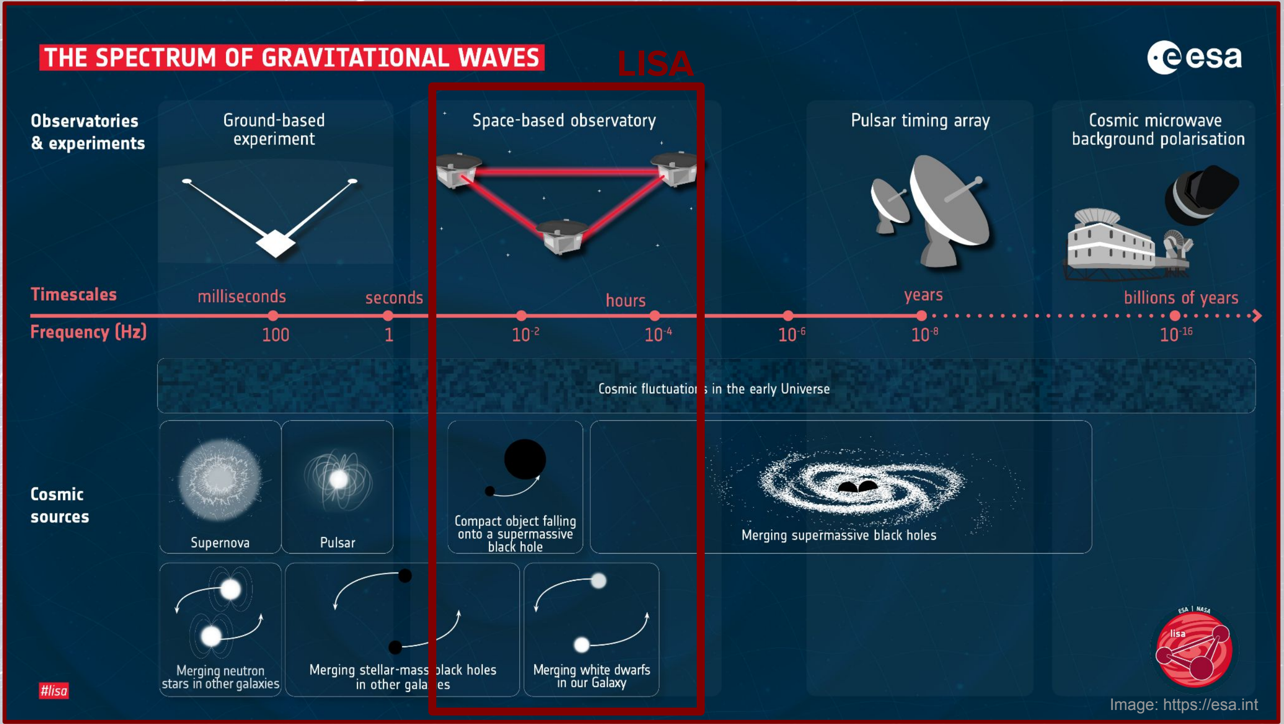


Image: https://esa.int

# Inspiraling galactic binaries

- LISA will be able to observe inspiraling systems for an extended period of time.

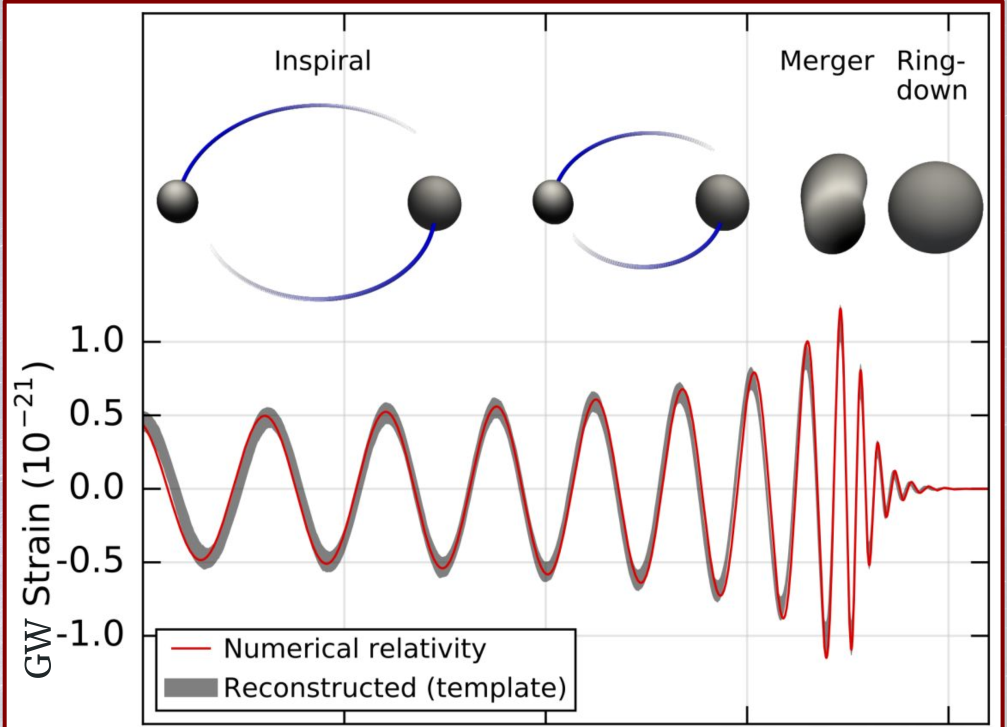



Image: LSC & Virgo, PRL 116(2016)061102.

# Inspiraling galactic binaries

- LISA will be able to observe inspiraling systems for an extended period of time.
- In these timescales, perturbations to orbital motion aggregate to produce measurable effects on the gravitational waveform.
- It is therefore important to consider a large variety of physical effects, such as *eccentricity*, *spin precession, magnetic field* interaction and *tides*.

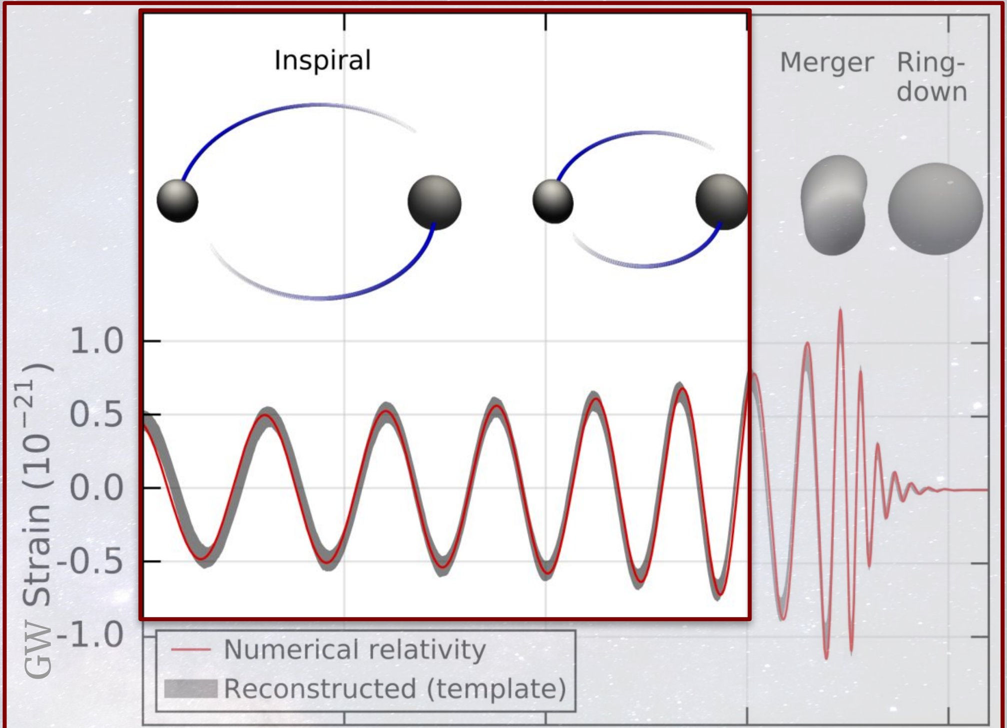
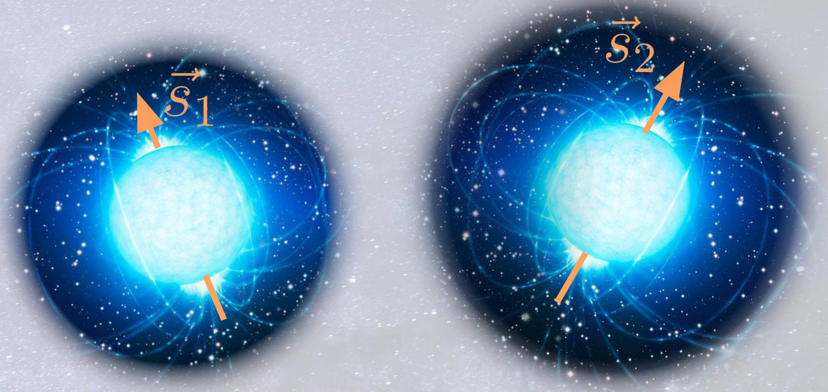


Image: LSC & Virgo, PRL 116(2016)061102.

# **Magnetism** in binary dynamics

We assume:

- Post-Newtonian point-like equations of motion, up to **2.5PN** (harmonic coordinates; no spin-gravity coupling; see e.g. Blanchet 2014);
- A ‘fossil’ magnetostatic field that is rigidly frozen into each star, **dipolar** and aligned with the spin axis;
- Perturbing magnetic dipole interaction potential;



# Results and conclusions

- We solve the EOM perturbatively. The GW polarization modes $h_+$ and $h_\times$ are obtained from the quadrupole formula evaluated with the newly-acquired orbital trajectories.
- **Magnetism will manifest as a frequency shift** signature in the GW modes (Figure): the dominant contribution is a distinct linear shift on each harmonic, directly **proportional to the magnetic energy** of the system. Fainter oscillatory terms may also be induced whenever the magnetic axes precess.

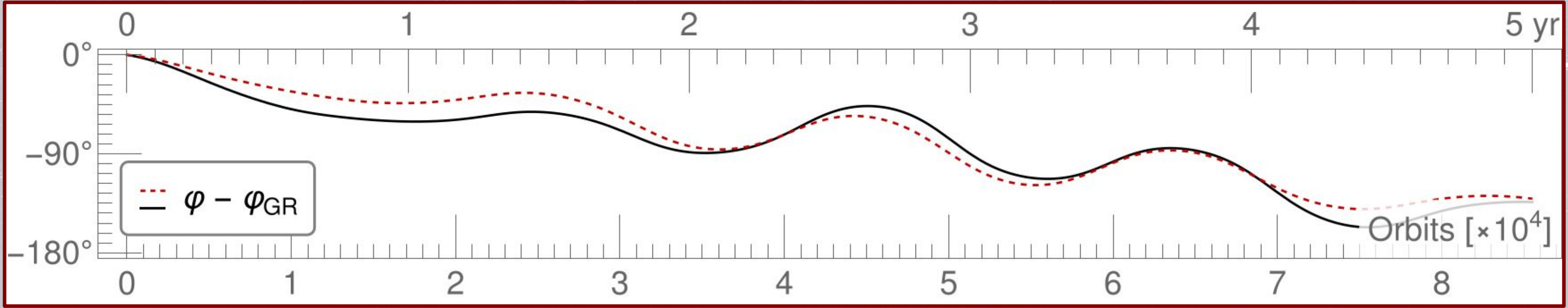



Figure. Magnetic contribution to the phase of the GW modes $h_+/h_\times$, in the monochromatic description.

# Thank you!

# EXTRA: LISA vs LVK

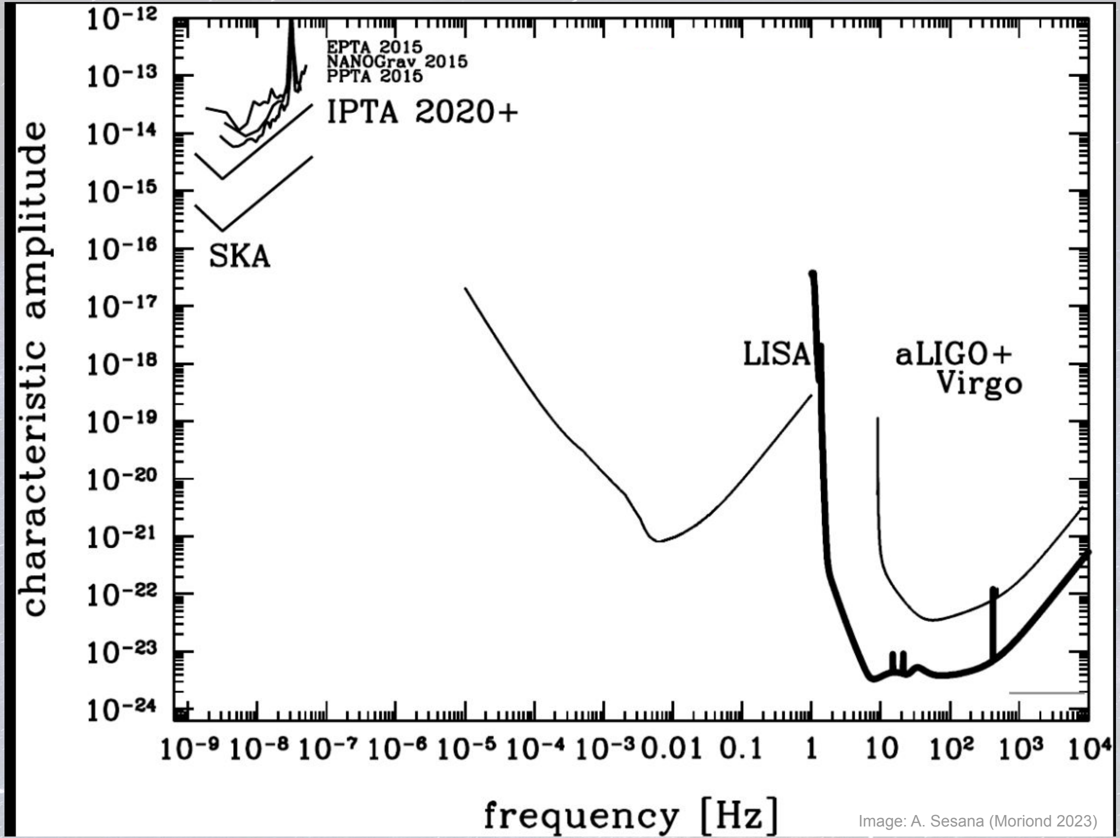



Image: A. Sesana (Moriond 2023)

# EXTRA: main sources

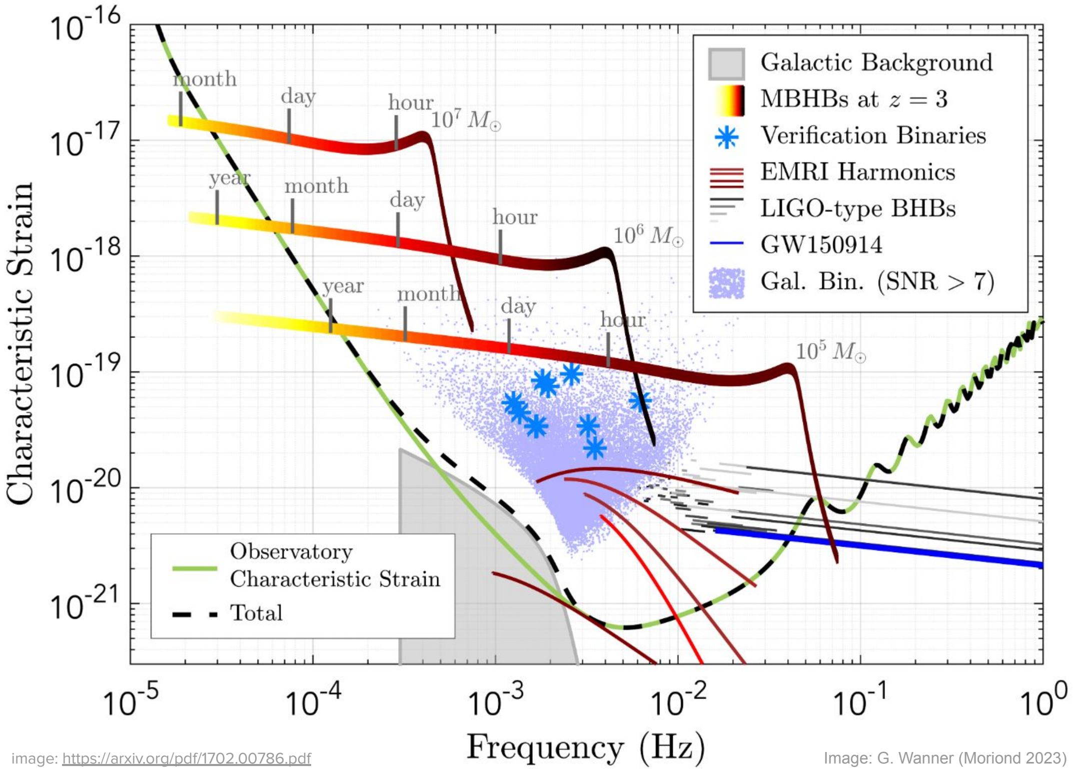
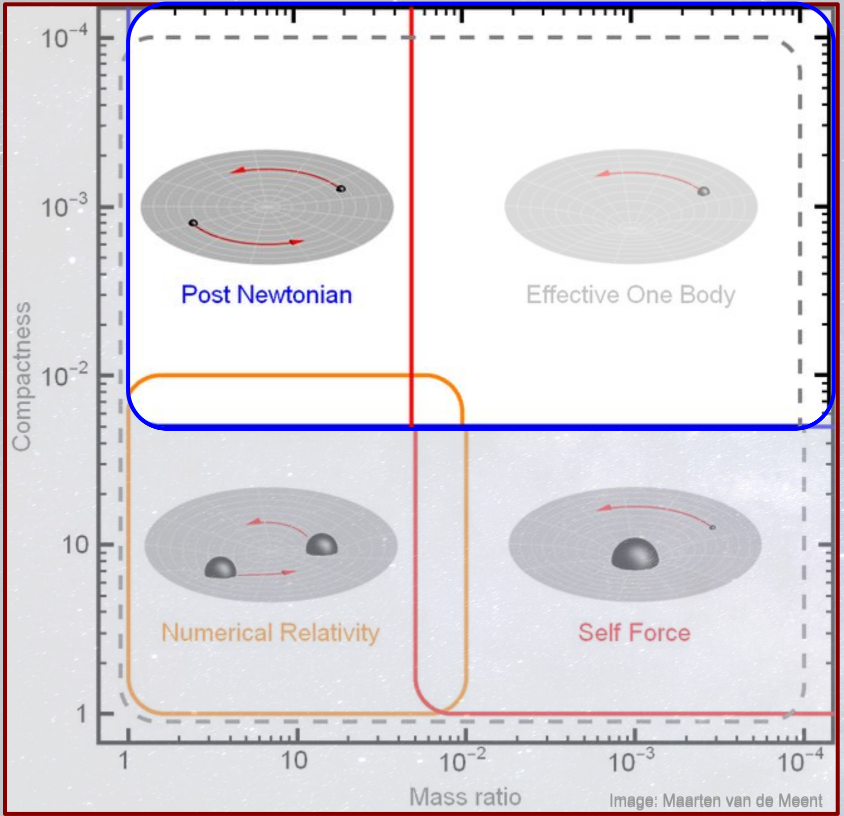



image: https://arxiv.org/pdf/1702.00786.pdf

Image: G. Wanner (Moriond 2023)

# EXTRA: PN expansion




## Post-Newtonian approximation:

- The metric tensor is expanded in powers of

$$\frac{1}{c^2}\frac{Gm}{r} \sim \frac{v^2}{c^2} \ll 1$$

- The resulting equations of motion (*harmonic coordinates*) can be treated as corrections to Newtonian gravity [see e.g. Blanchet 2014]:

$$\begin{aligned}\boldsymbol{a}_1 = &-\frac{Gm_2}{r_{12}^2}\boldsymbol{n}_{12} \\ &+\frac{1}{c^2}\left\{\left[\frac{5G^2m_1m_2}{r_{12}^3}+\frac{4G^2m_2^2}{r_{12}^3}+\frac{Gm_2}{r_{12}^2}\left(\frac{3}{2}(n_{12}v_2)^2-v_1^2+4(v_1v_2)-2v_2^2\right)\right]\boldsymbol{n}_{12}\right. \\ &\qquad\left.+\frac{Gm_2}{r_{12}^2}\left(4(n_{12}v_1)-3(n_{12}v_2)\right)\boldsymbol{v}_{12}\right\} \\ &+\frac{1}{c^4}\left\{\left[-\frac{57G^3m_1^2m_2}{4r_{12}^4}-\frac{69G^3m_1m_2^2}{2r_{12}^4}-\frac{9G^3m_2^3}{r_{12}^4}\right.\right. \quad +(\cdots)\end{aligned}$$

# Role of Strangeness in Neutron Stars

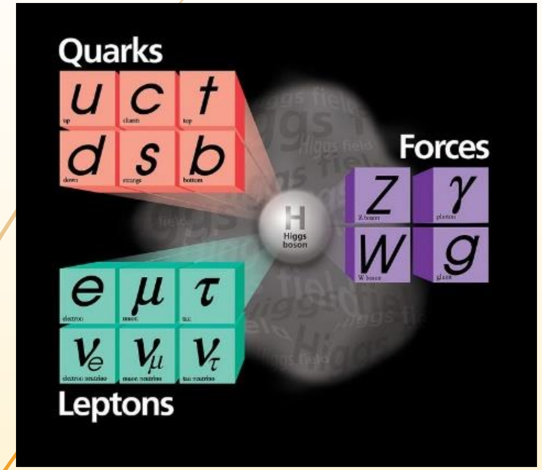
Mahboubeh Shahrbaf

Uniwersytet Wrocławski

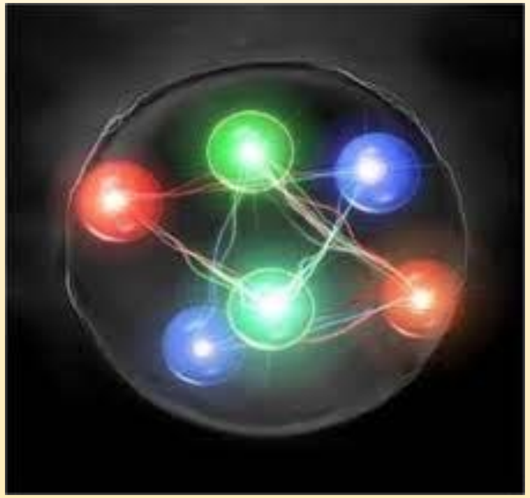
Thematic school **Gravitational wave emission from proto-neutron stars and neutron star mergers**
(GWsNS-2023)

5-9 June 2023

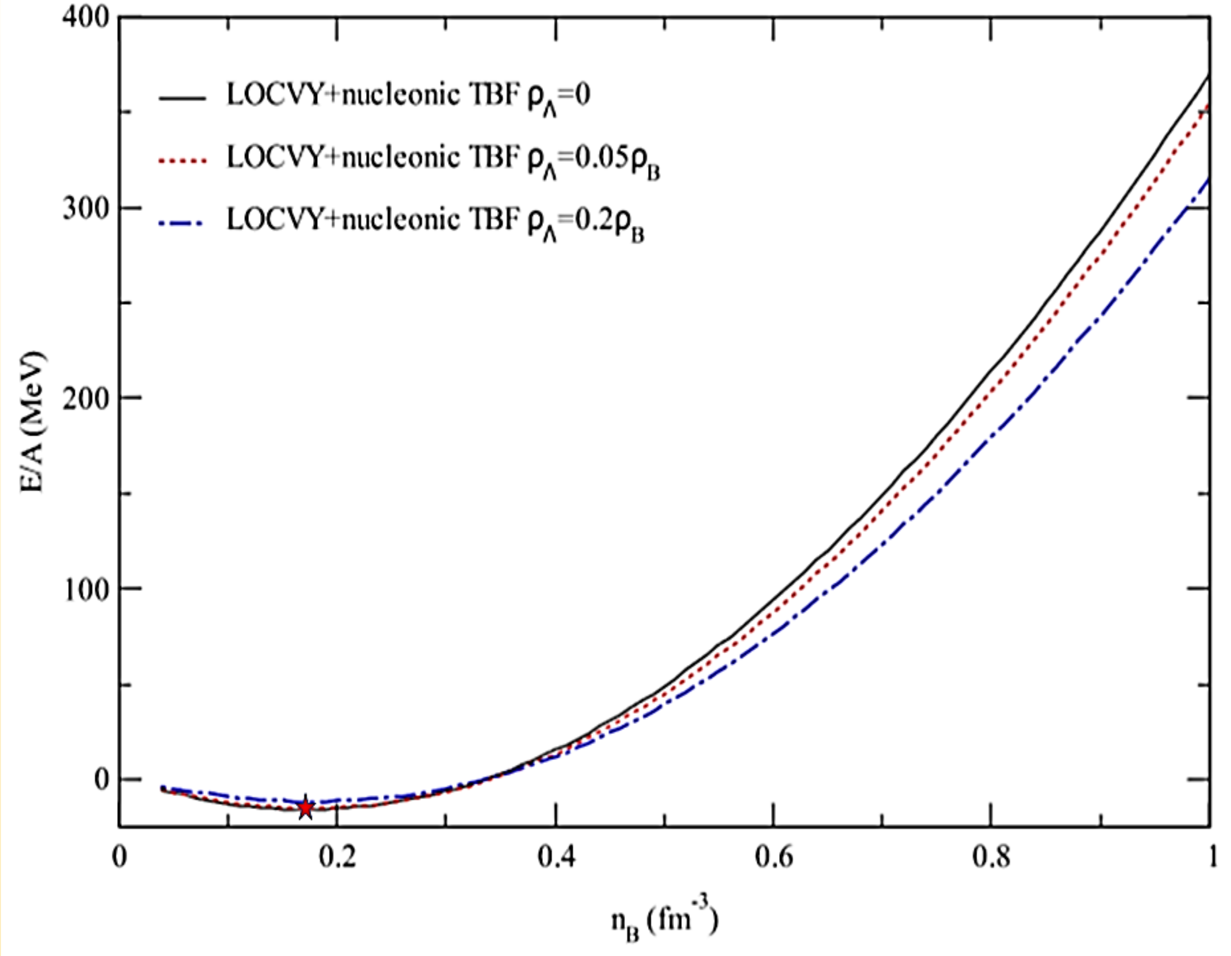
# Strangeness in Neutron Stars




- ❑Hyperons
- ❑Strange quark matter
- ❑Multi-quark states (Sexaquark (uuddss))

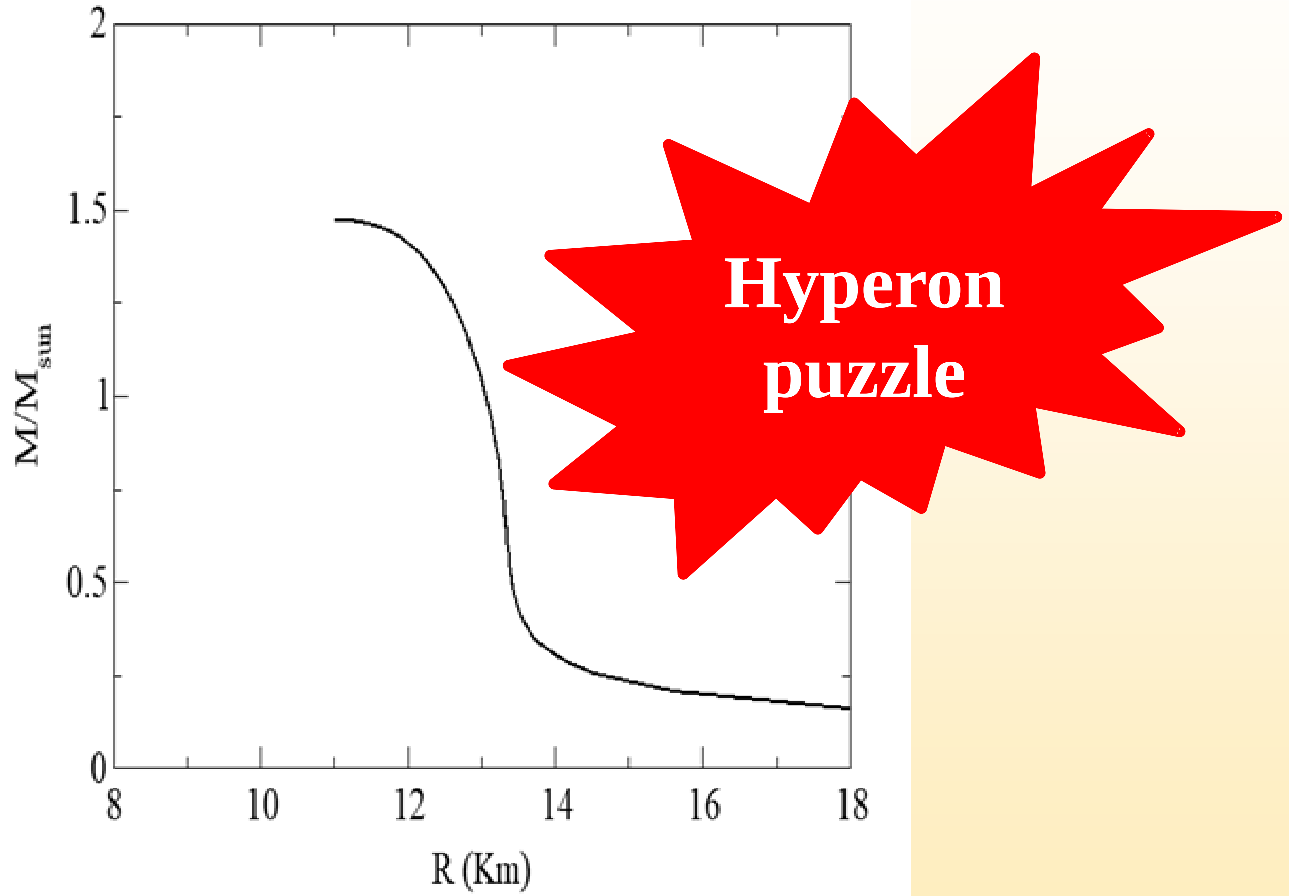


# Including Hyperon in a Variational method



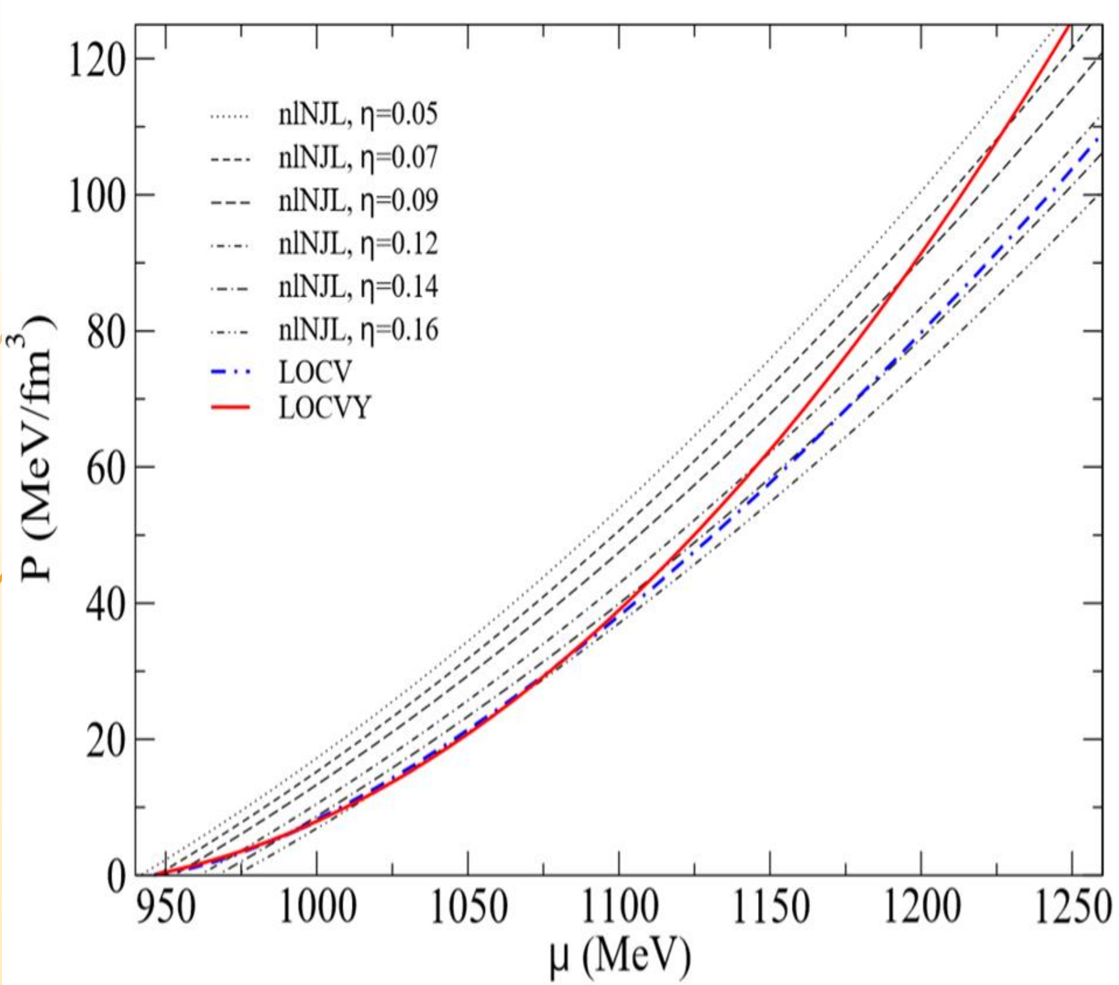

**M. Sh**, H. R. Moshfegh, M. Modarres, PRC **100**, no.4, 044314 (2019)
**M. Sh**, H. R. Moshfegh and M. Modarres, Phys. Rev. C **100**, no.4, 044314 (2019)

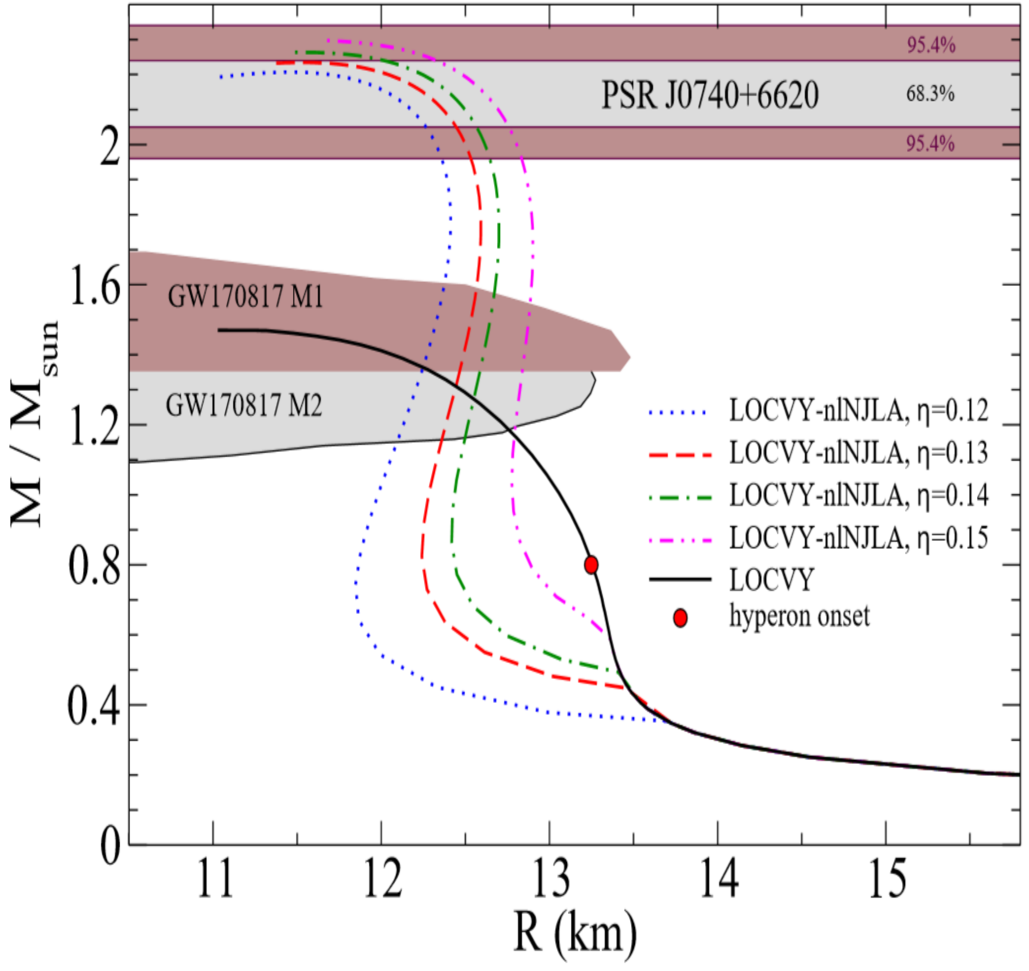
# TOV equations and Mass-Radius relation




In RMF models, the NY and YY couplings are adjusted in such a way that there is no hyperon puzzle. Indeed, vector mesons generate repulsion at short distances

# Phase Transition from LOCVY to nlNJL model
## As a Solution to Hyperon Puzzle

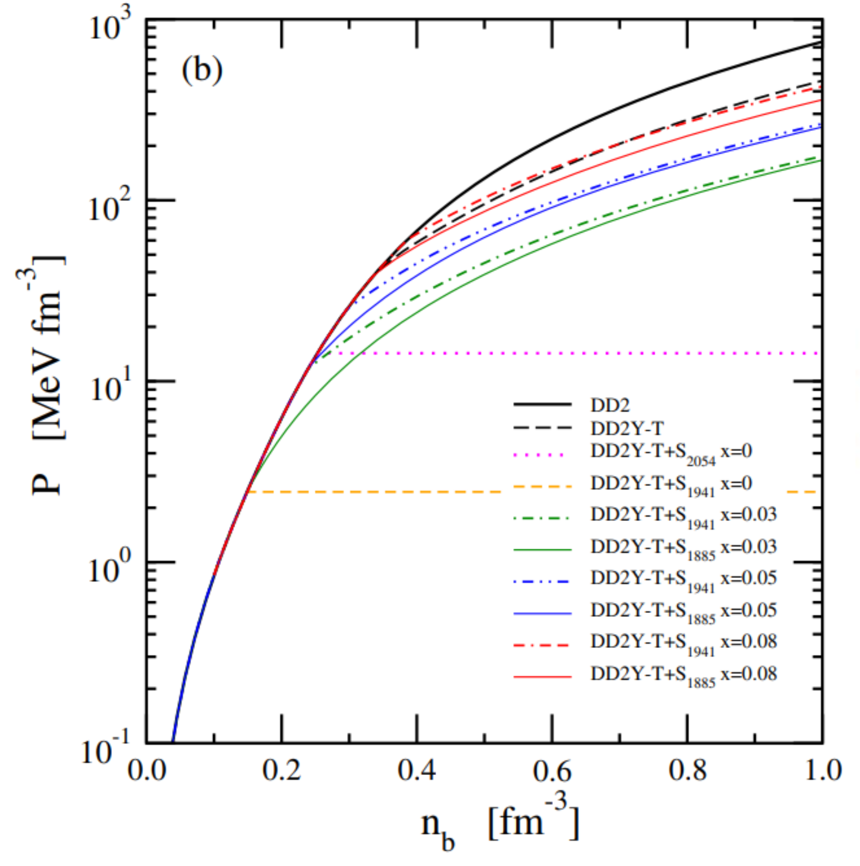


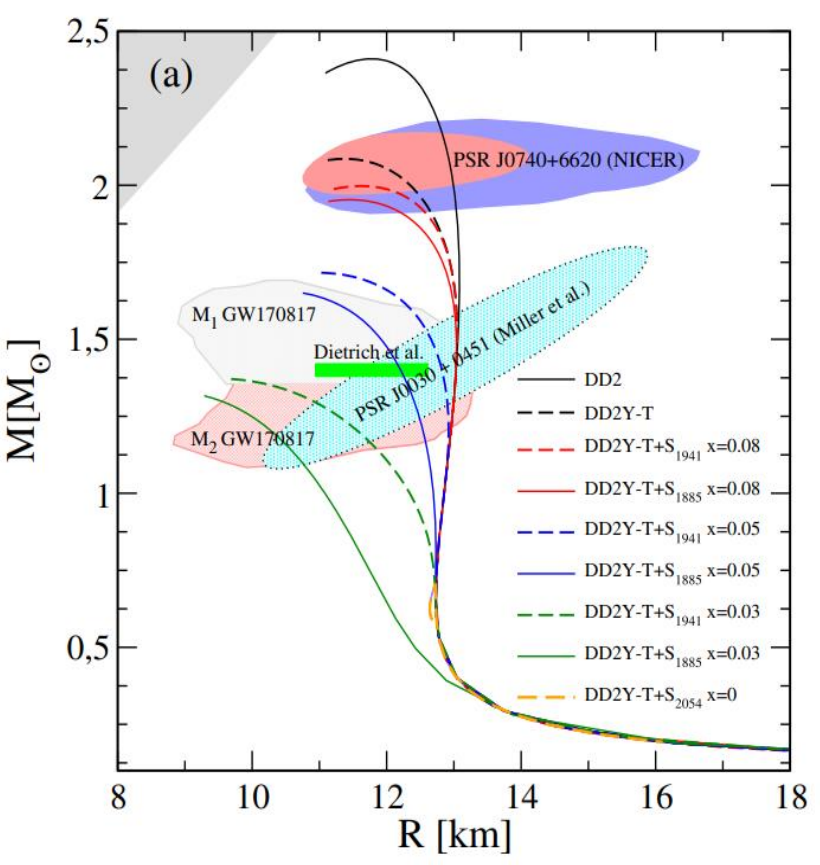



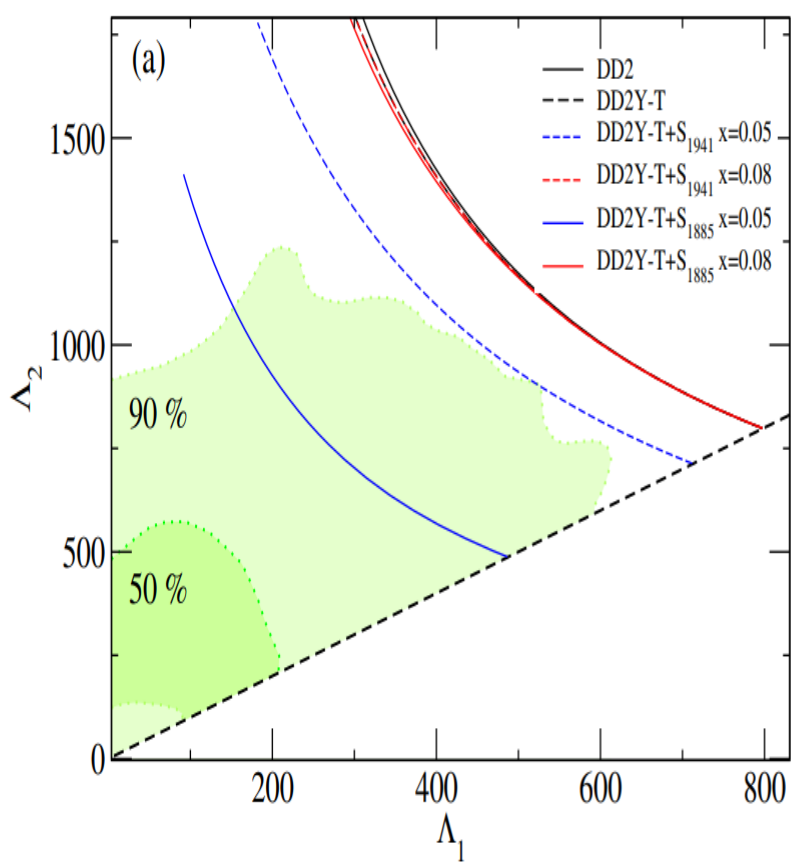

**M. Sh**, D. Blaschke, A. G. Grunfeld, and H. R. Moshfegh, Phys. Rev. C 101, 025807 (2020)
**M. Sh**, D. Blaschke, and S. Khanmohamadi, J. Phys. G 47, 115201 (2020)

# Including strangeness in RMF model

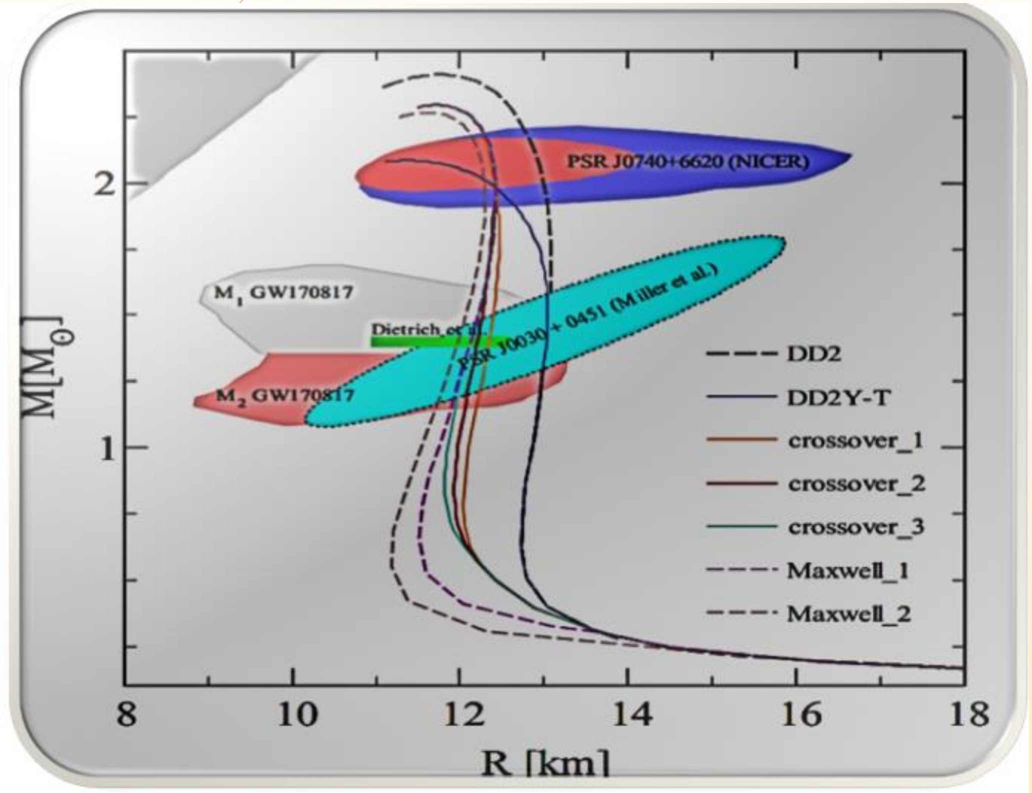
## Hyperons and Sexaquark in DD2 model

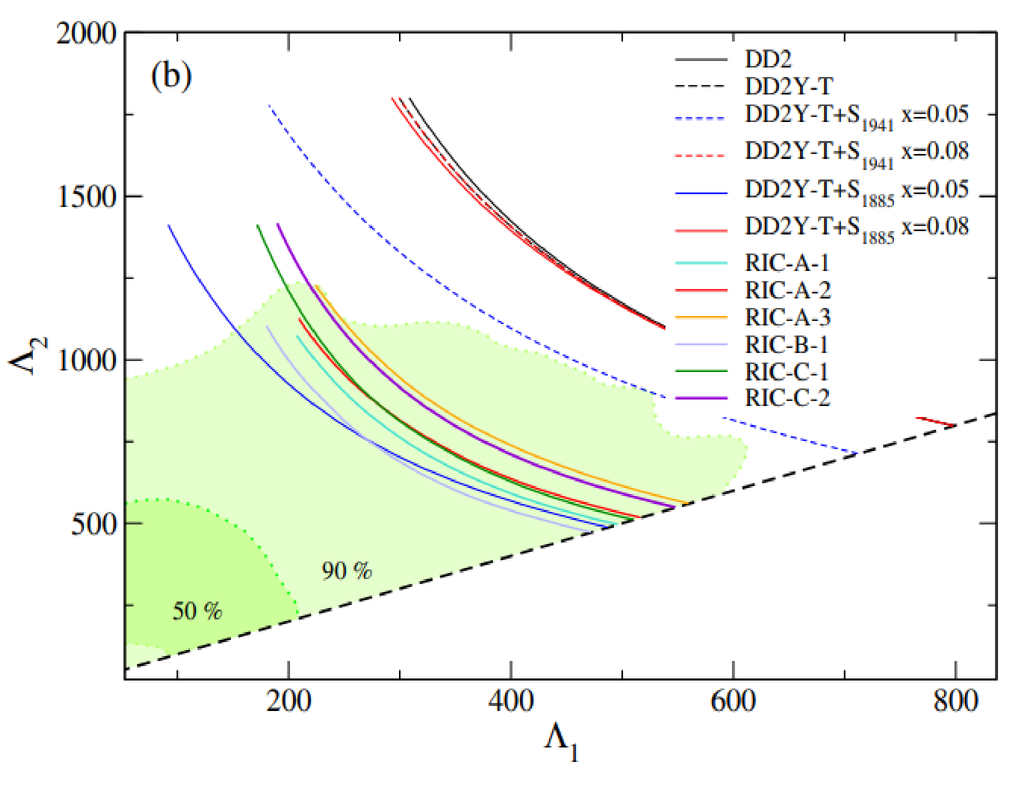


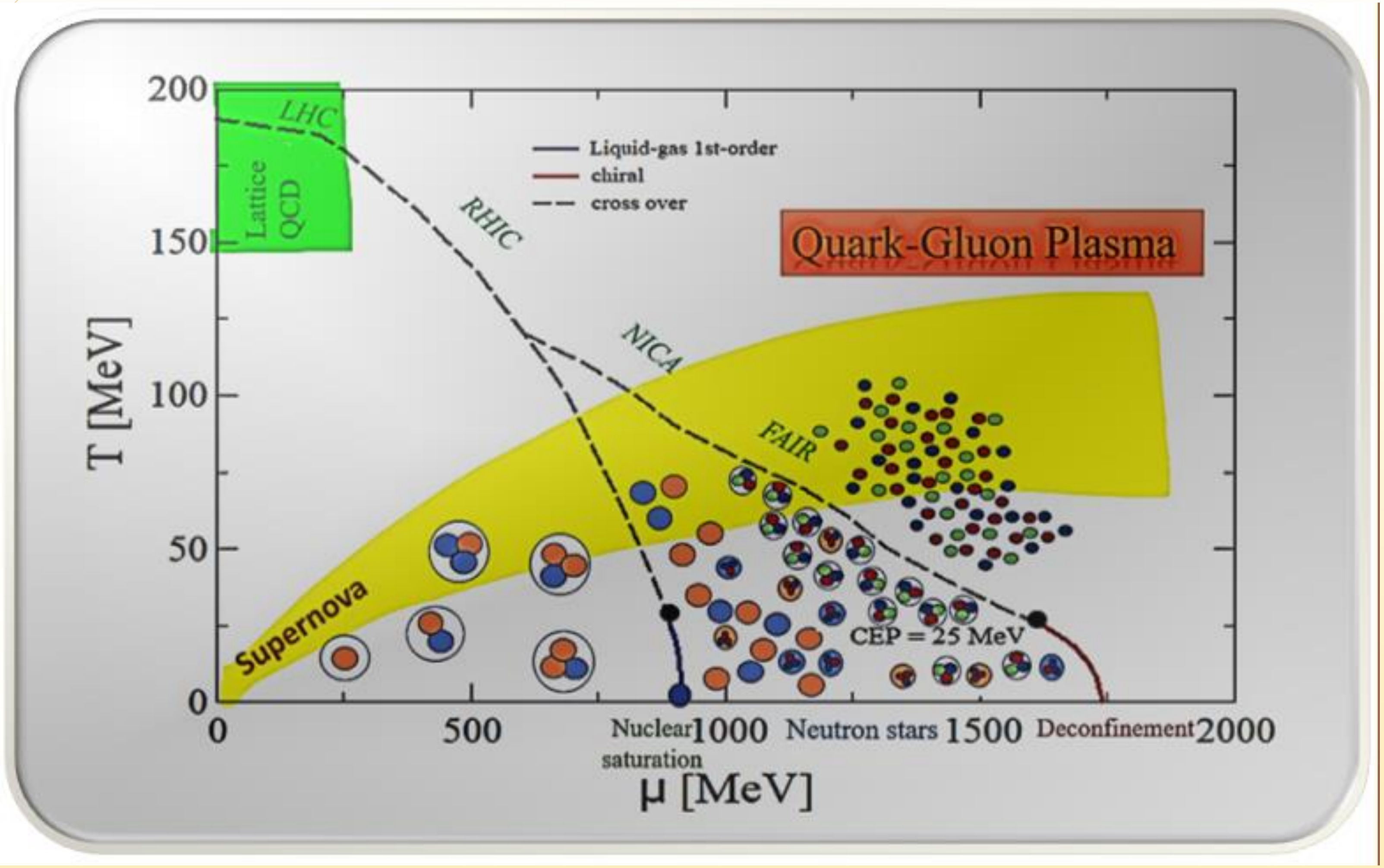
# All Observational Constraints from NSs are fulfilled in Hybrid model




**M. Sh**, D. Blaschke, S. Typel, G. R. Farrar and D. E. Alvarez-Castillo,
Phys. Rev. D **105**, 103005 (2022)

# Outlook: Investigating the Role of Strangeness in QCD Phase Diagram




**M.Sh** [arXiv:2303.03030 [nucl-th]]

Thank you

UNIVERSITY
OF WARSAW

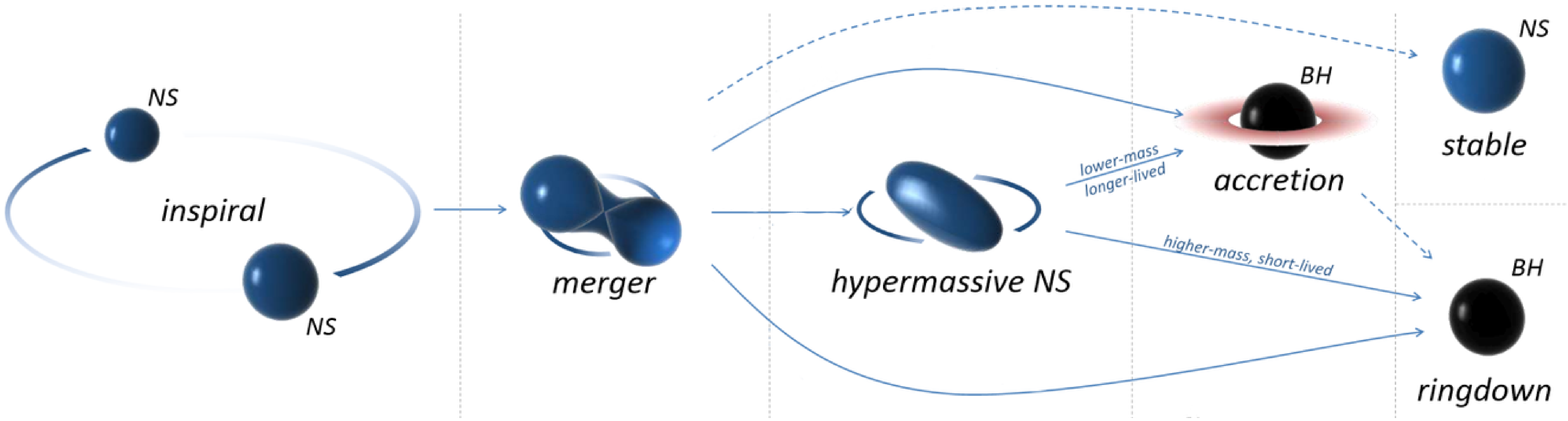
# STABILITY OF HYPERMASSIVE NEUTRONS STARS AGAINST A PROMPT COLLAPSE

**Paweł Szewczyk**

in collaboration with: Dorota Rosińska, Pablo Cerda-Duran

# Why differentially rotating NS?

- Core-collapse supernova remnant

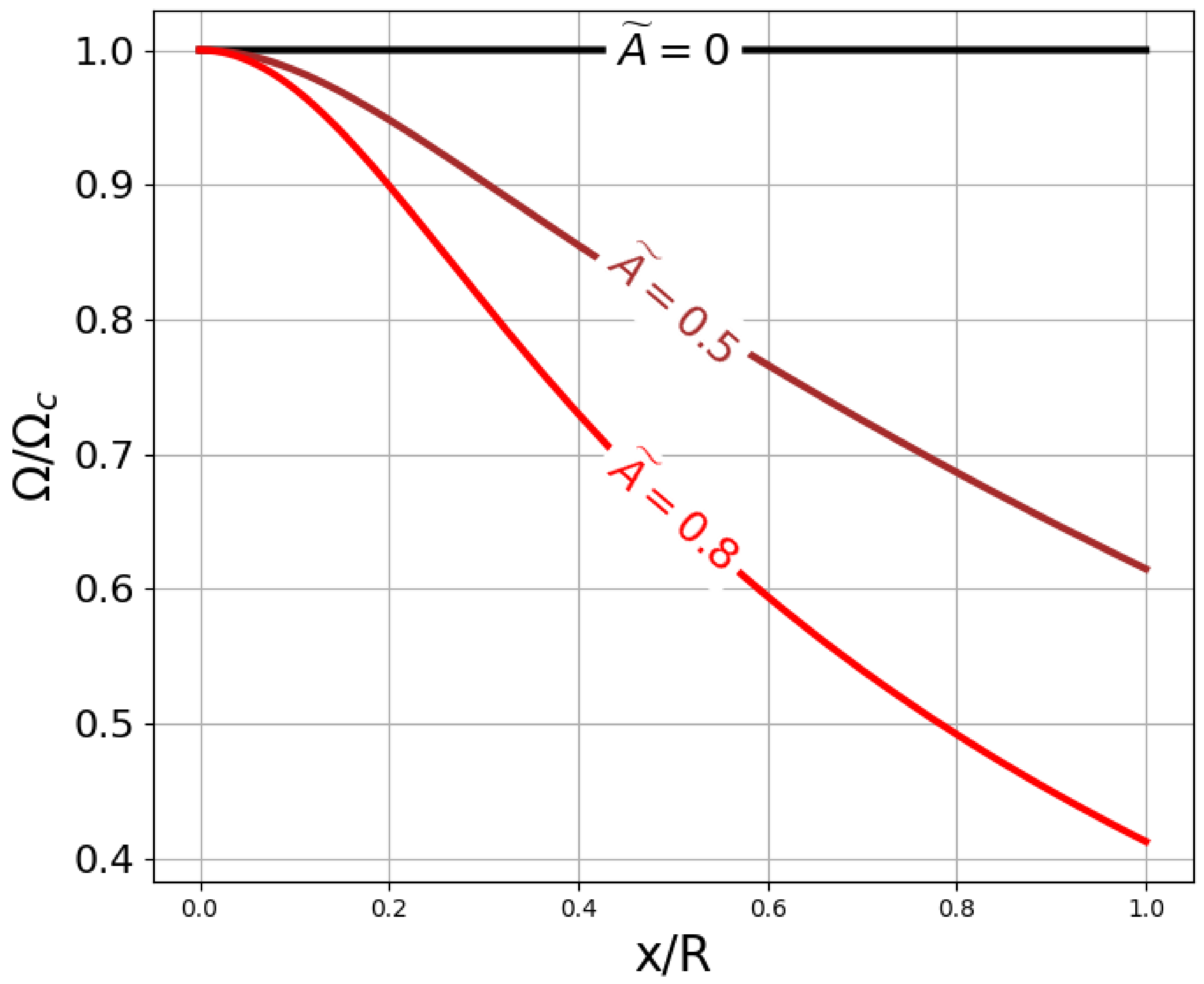



(Bartos, Brady, Marka 2013)

- BNS merger remnant

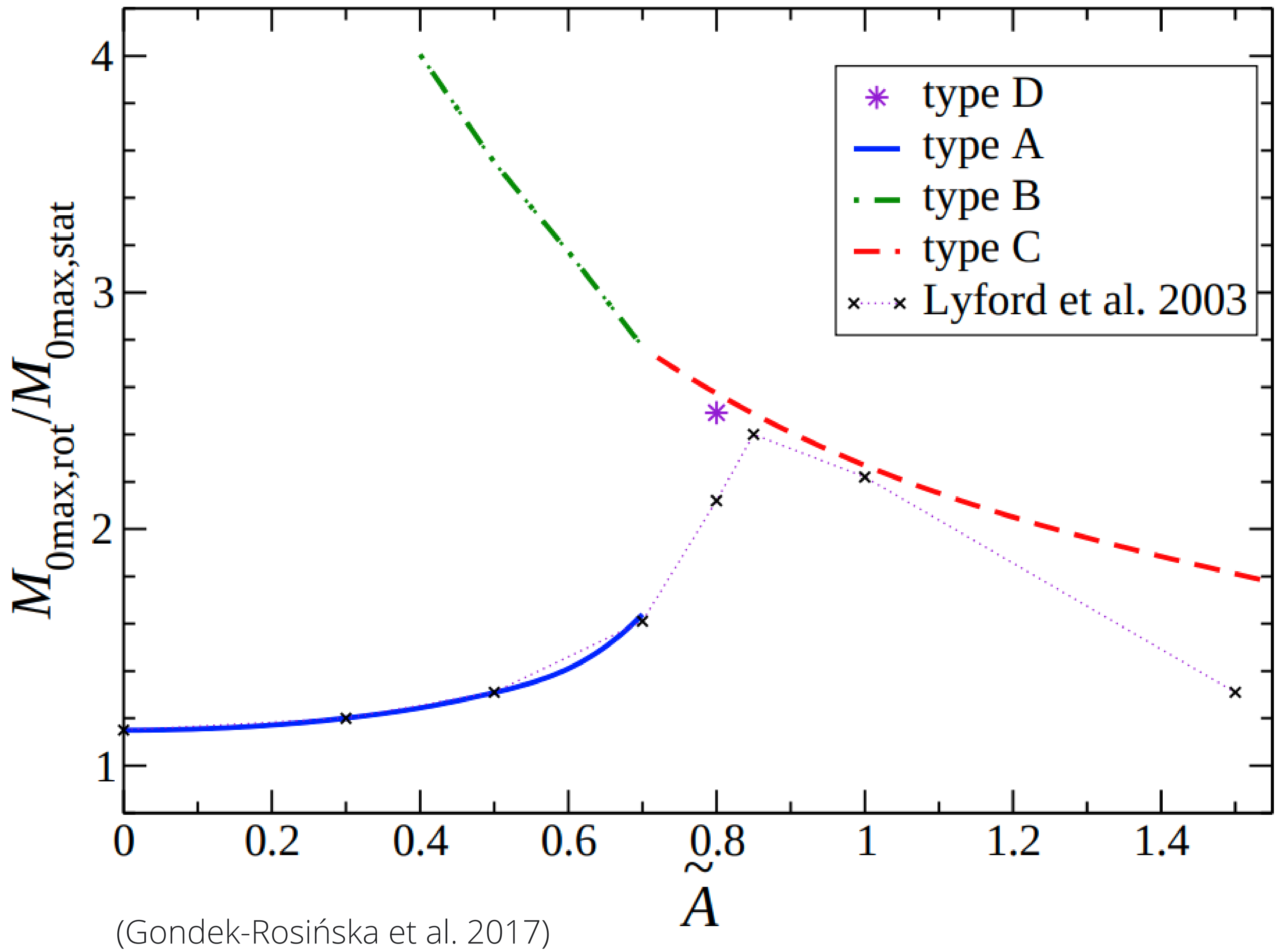
# Methodology

- Relativistic **FlatStar** code for axisymmetric stationary NS models with differential rotation (Ansorg, Gondek-Rosinska, Villain 2009)
- **Polytropic EOS** ($P = K\rho^2$)
- **j-const** (KEH) rotation law (Komatsu et al. 1989), consistent with core-collapse remnant
- **CoCoNuT** code for 2D hydrodynamics
- **Cactus** framework for 3D hydrodynamics




Rotation profiles in equatorial plane for different degrees of dif. rotation

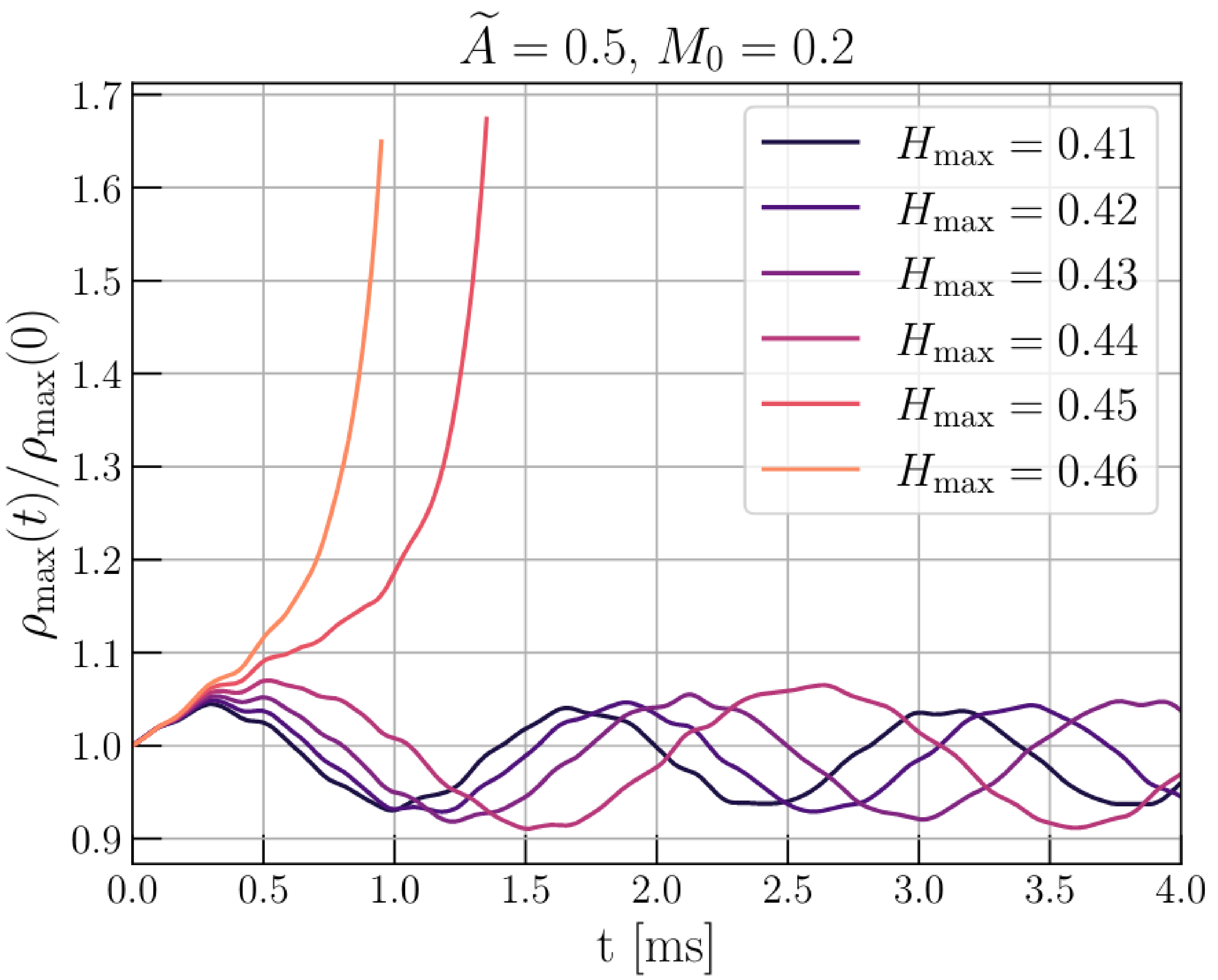
# Maximum mass



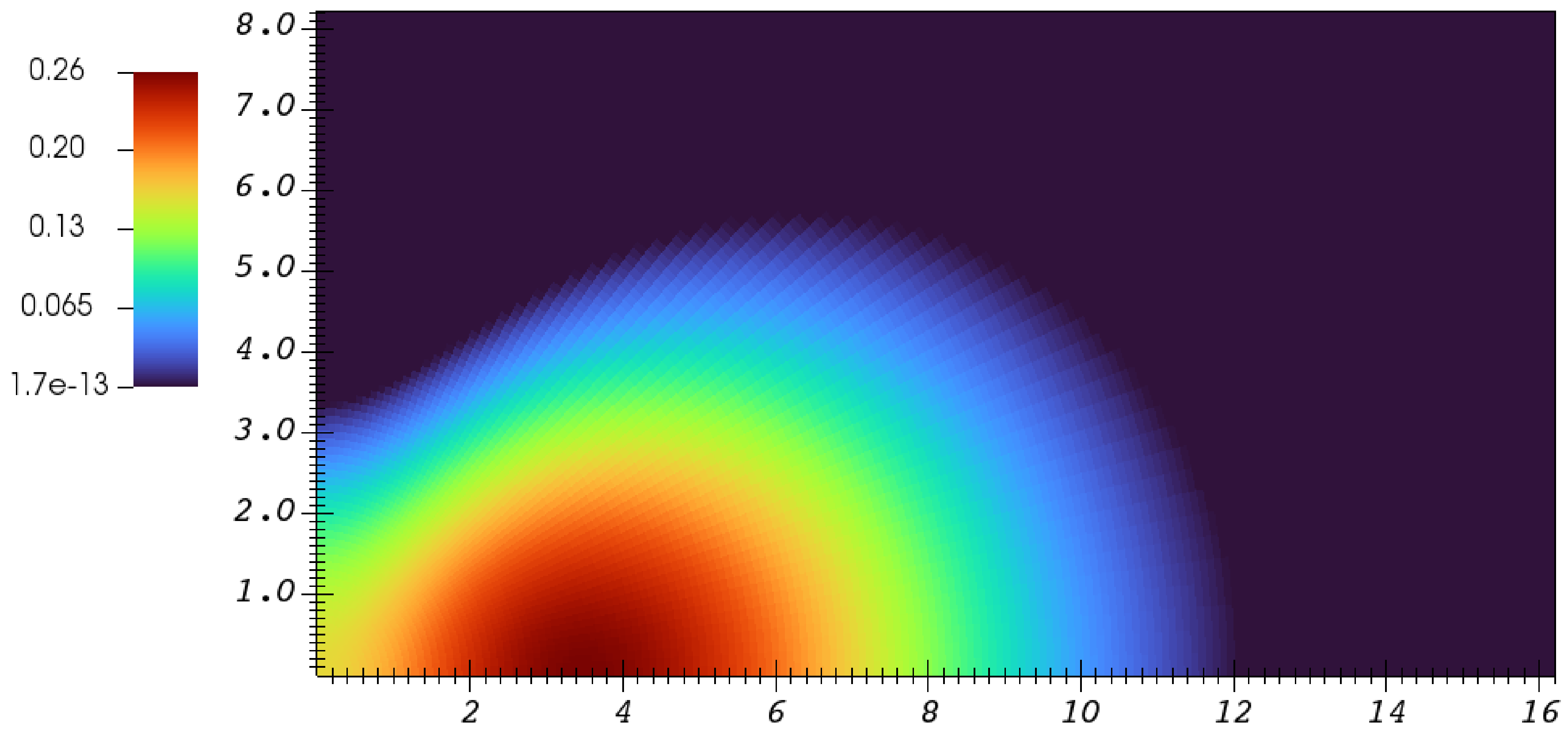

(Gondek-Rosińska et al. 2017)

- **Differential** rotation leads to larger possible masses than rigid rotation
- Maximum mass at a **moderate** degree of differential rotation
- Similar properties for different polytropes (Studzińska et al. 2016), strange stars (Szkudlarek et al. 2019) and realistic NS EOS (Espino and Paschalidis 2019)
- Are massive configurations dynamically **stable**?

# 2D simulations

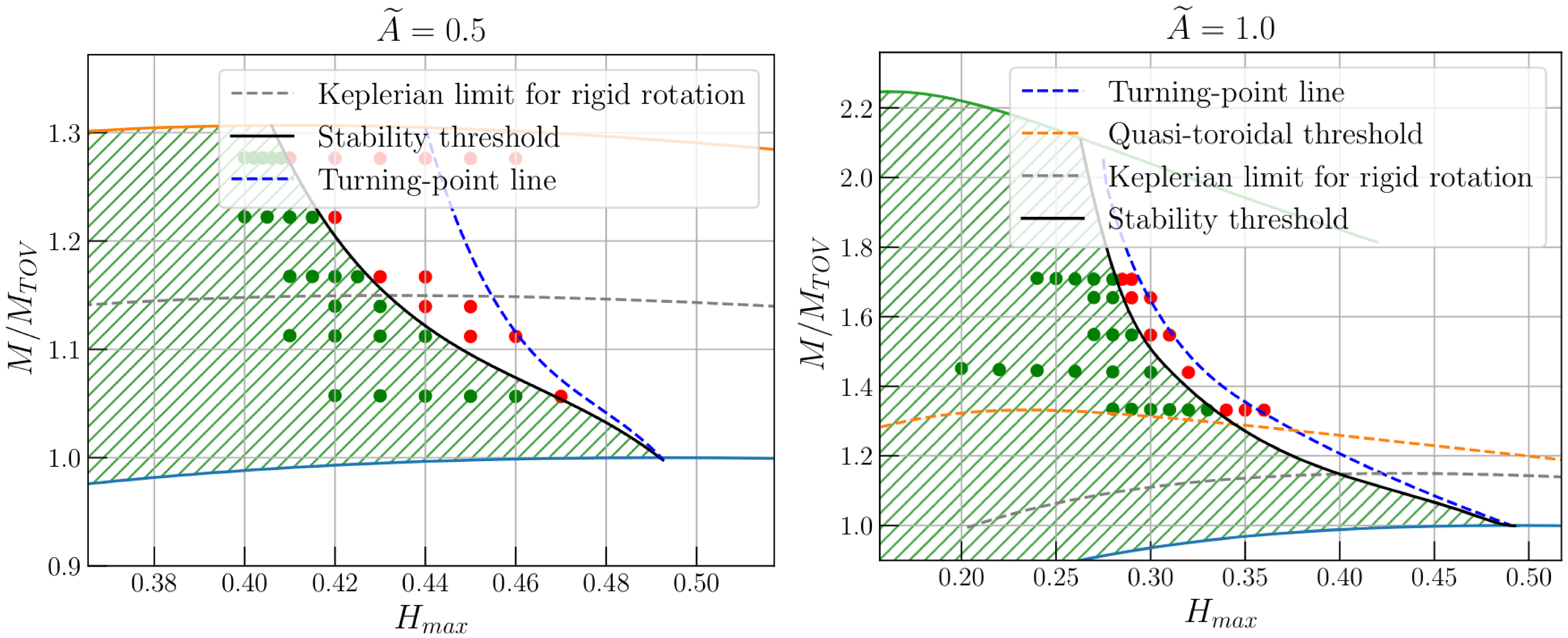



Maximal density evolution for stable and unstable cases




Initial data calculated by FlatStar (Axial symmetry, CFC approximation, Additional radial perturbations)

# Stability limit for differential rotation



# Summary

- Massive NS can be stabilized by **differential rotation**
- The most massive configurations can be estimated to be dynamically stable by the **turning-point criterion**
- Maximum mass for a stationary solution is ~4M_TOV
- We found stable configurations with M=2M_TOV

Future work:

- 3D simulation (non-radial modes)
- Realistic EoS
- Types B and D

# Bayesian inference with hybrid equations of state

**Antoine Pfaff**

Institut de physique des 2 infinis, Lyon, France

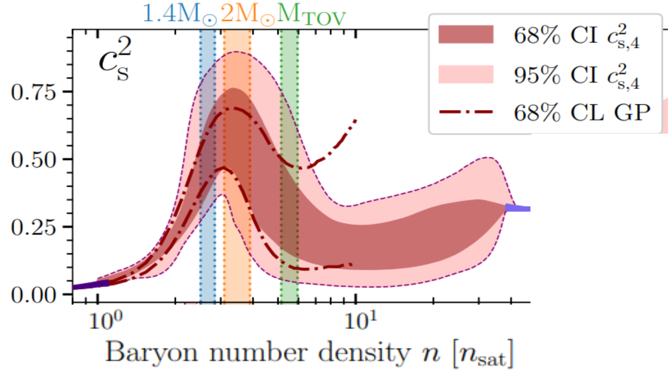
Supervised by H. Hansen (IP2I, Lyon) J. Aichelin (SUBATECH, Nantes)

# Bayesian inference of the NS EoS

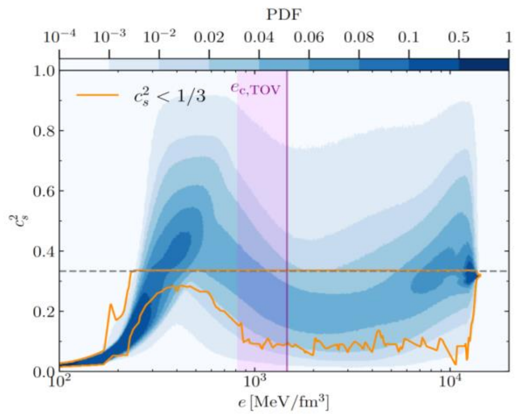
- Hydrostatics equilibrium in compact stars is ruled by the TOV equations

Equation of state $P(\rho)/c_s(\rho)$ ⟺ Macroscospic properties $M, R, \Lambda$

*Arxiv: 2303.11356 (Annala et al.)*




*S Altiparmak, C Ecker, and L Rezzolla*
The Astrophysical Journal Letters (2022)




Objectives:

- Implement the bayesian method with microscopic-informed models
- Compare the purely nuclear vs hybrid hypotheses, search for signatures

# Bayesian method

- Generate a large number of models
  - Purely nuclear based on the "metamodel" expansion (Margueron et al. 2018)
  - Hybrid models based on the nucleonic metamodel +
    - First order phase transition towards NJL quark model (Pfaff et al.)
    - Smooth crossover with the quarkyonic model (McLerran et al., Margueron et al 2021)

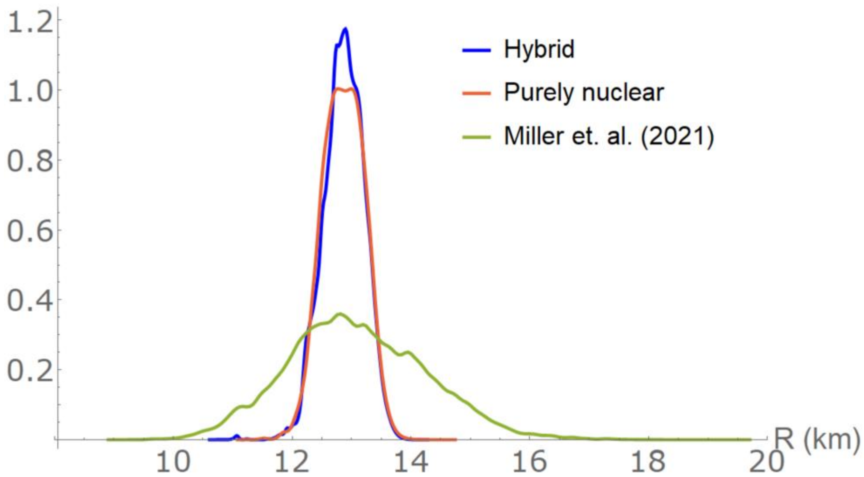
- Model selection based on the reproduction of physical constraints
  - Low density $\chi$EFT energy calculations (NM + SM)
  - Maximal mass compatible with J0740+6620 : $M = 2.08 \pm 0.07 M_{\odot}$
  - Tidal deformabilities inferred from GW170817

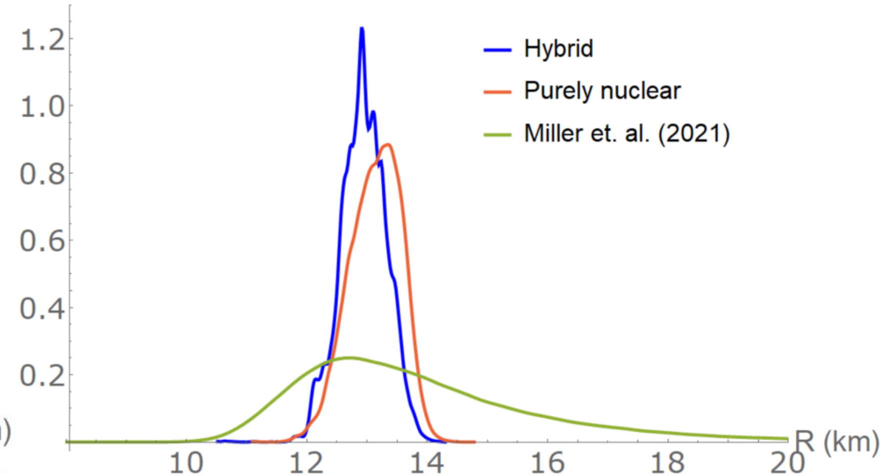
*J. Margueron, R. Homann Casali, and F. Gulminelli, Phys Rev C **97**, 025805 (2018)*
*Antoine Pfaff, Hubert Hansen, and Francesca Gulminelli Phys. Rev. C **105**, 035802 (2022)*
*Larry McLerran and Sanjay Reddy Phys. Rev. Lett. **122**, 122701 (2019)*
*Jérôme Margueron, Hubert Hansen, Paul Proust, and Guy Chanfray Phys. Rev. C **104**, 055803 (2021)*

# Neutron star radii

Comparison with estimations of the radius from the NICER mission

J0030+0451 : $M = 1.44 \pm 0.14 M_{\odot}$ J0740+6620 : $M = 2.08 \pm 0.07 M_{\odot}$



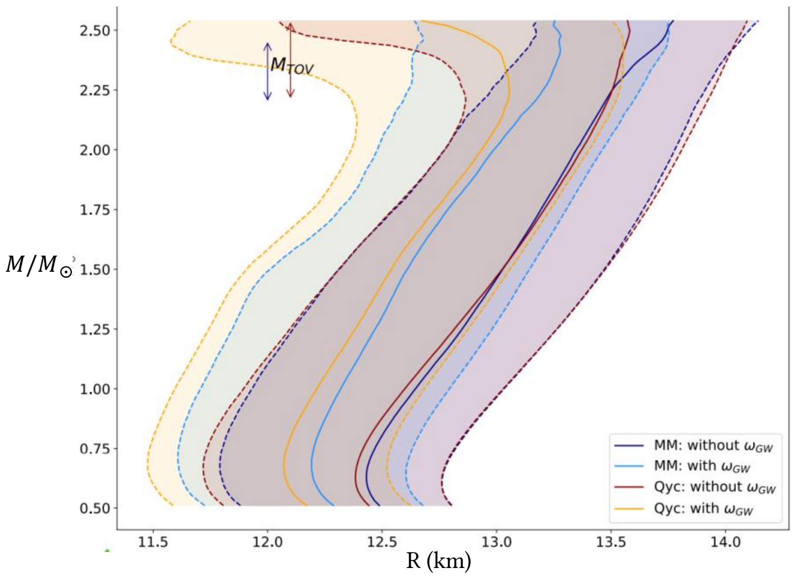




→ Both model assumptions are compatible with NICER data

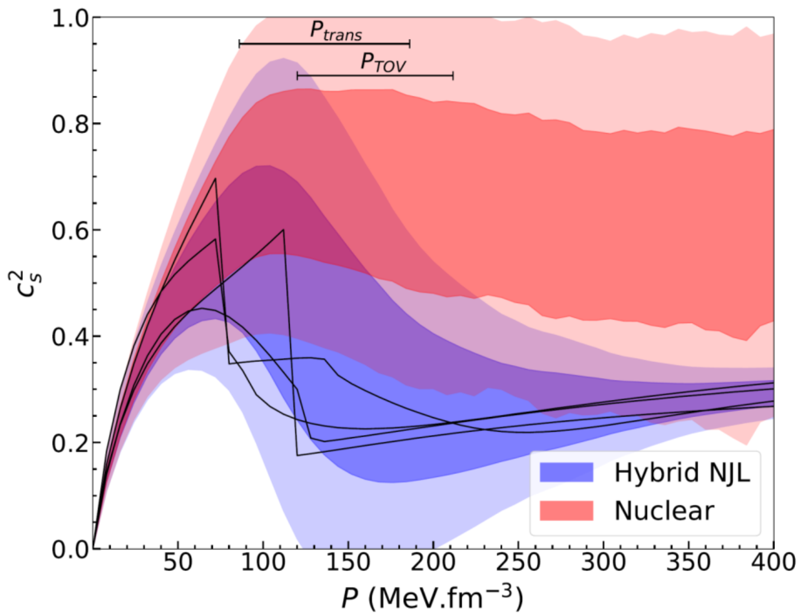
Inclusion of a quark PT has weak influence on the radii

*M. C. Miller et al 2021 ApJL* ***918*** *L28*

# Global EoS properties




*By courtesy of Mathis Moulin*



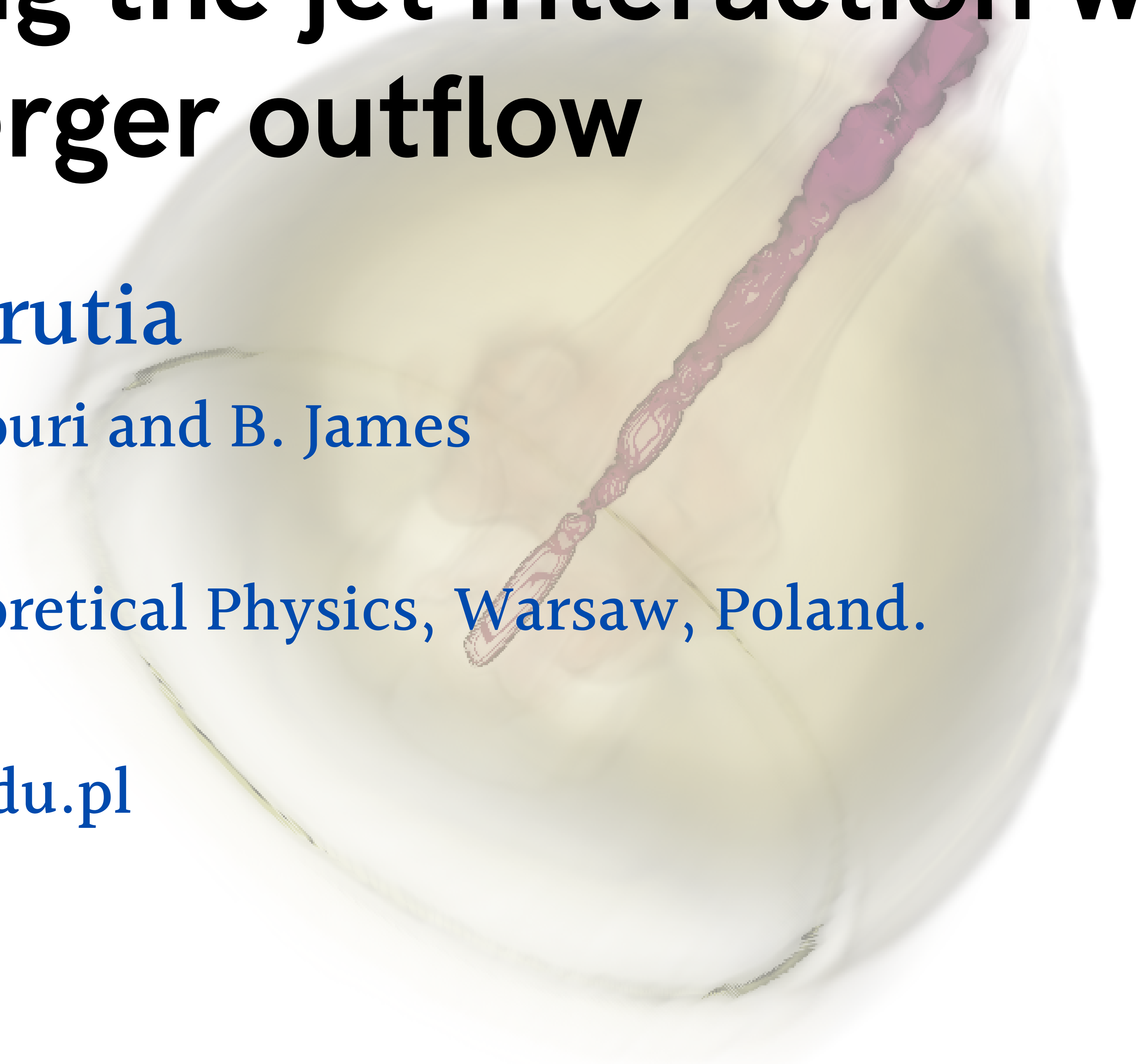

Star properties are driven by constraints rather than microscopic composition

Quark signatures are relegated to higher pressures/densities

⇨ Need for
- Better constraints on M/R/Λ (→ O4/Third gen GW detectors)
- New observables sensible to higher density behavior

# THANK YOU !!

# Following the jet interaction with a post-merger outflow



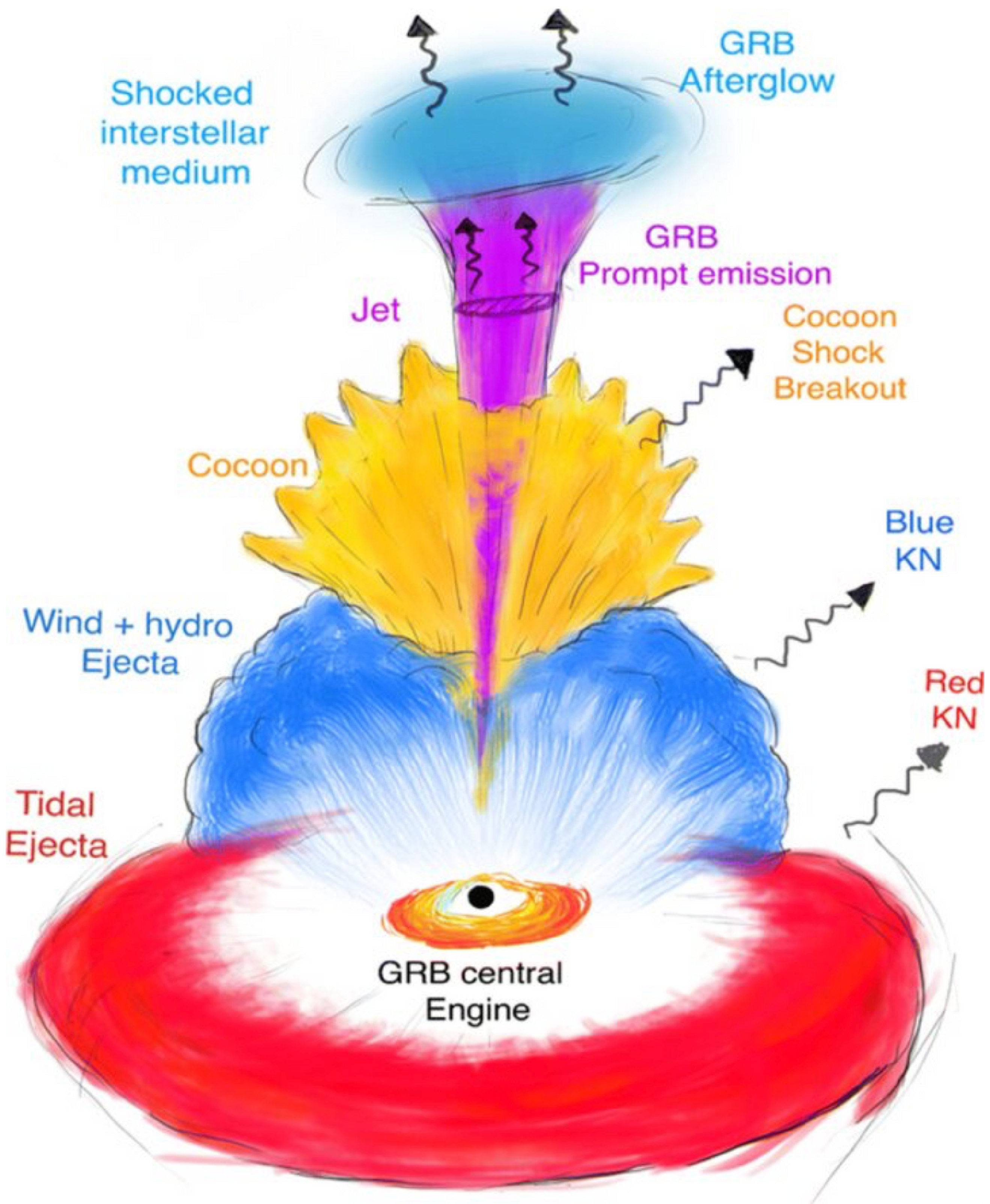

Gerardo Urrutia

A. Janiuk, F. Nouri and B. James

Center for Theoretical Physics, Warsaw, Poland.

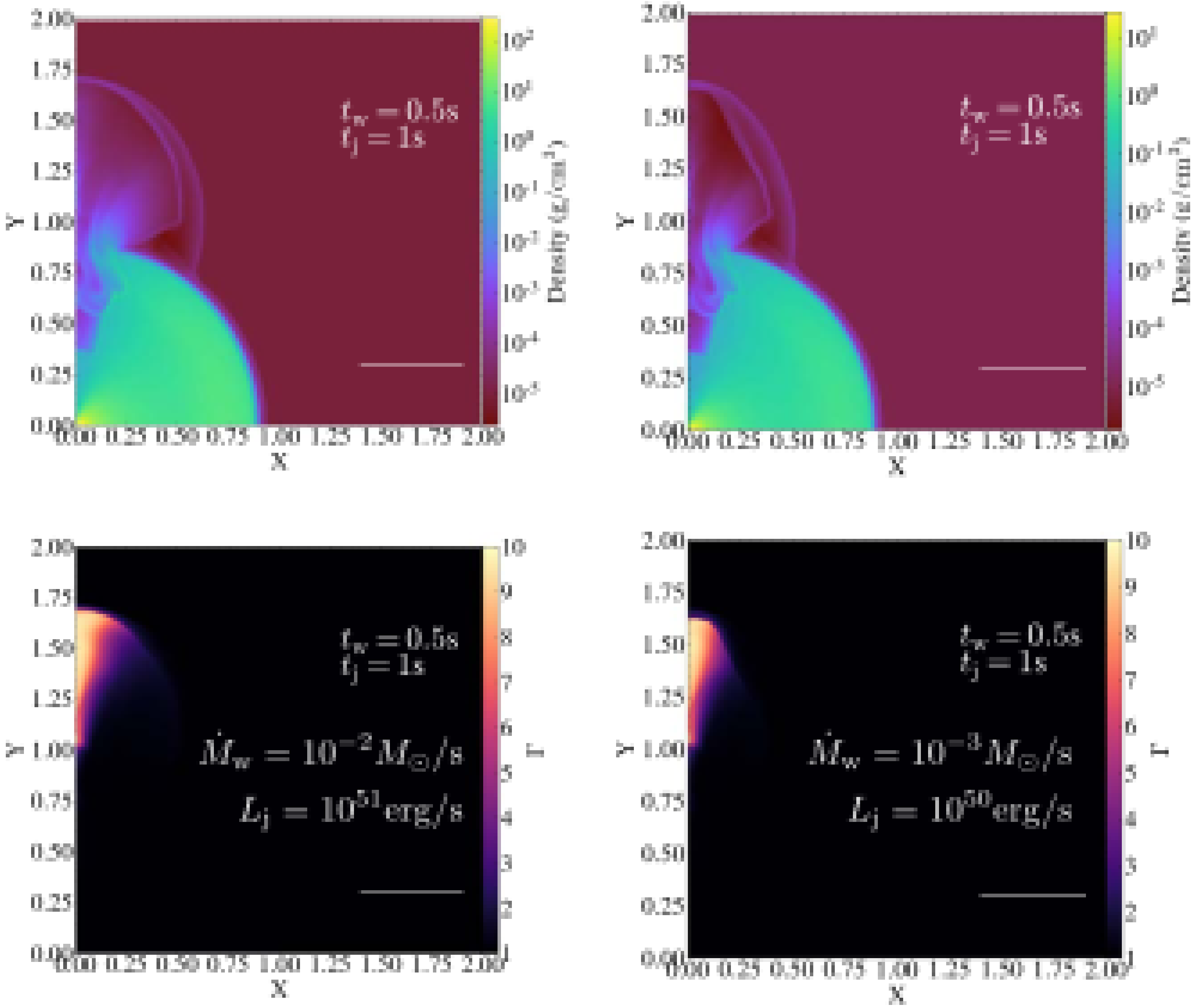
gurrutia@cft.edu.pl

# Short Gamma Ray Bursts

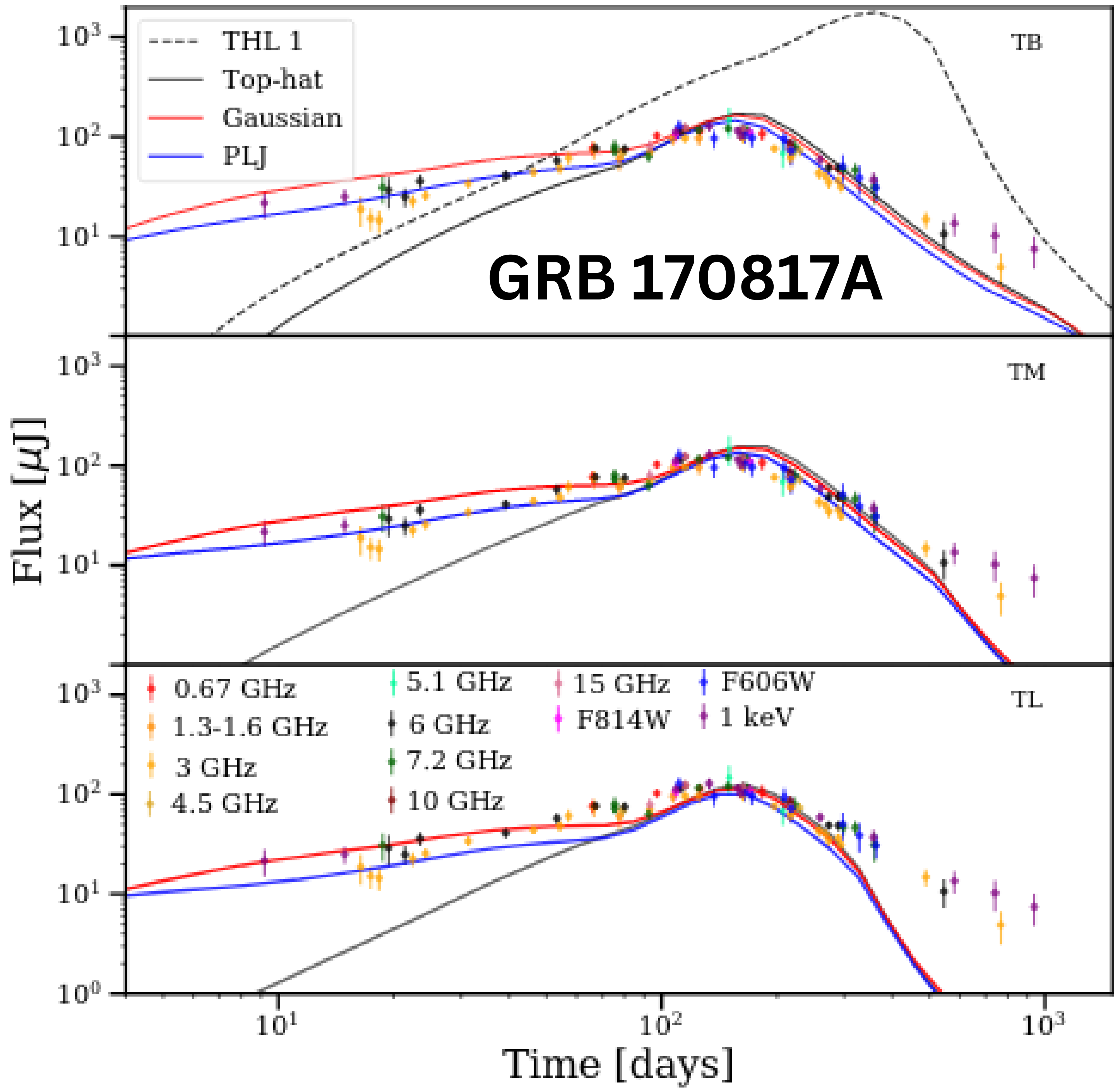



credits: Stefano Ascenzi

# Motivation:Jet Interaction is frecuently simplified




Murguia-Berthier, et. al., 2021

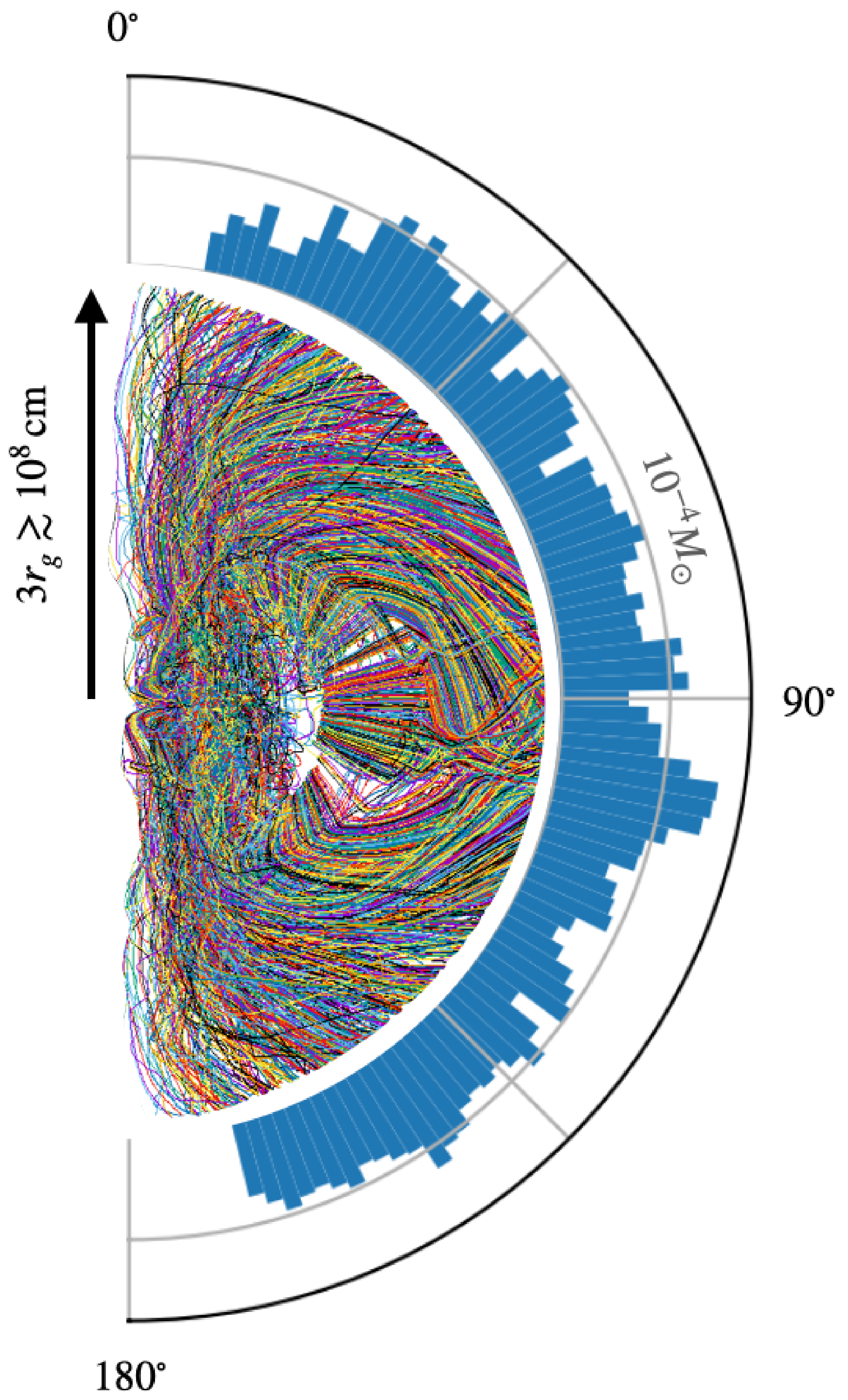



Urrutia, et. al., 2021

# Initial Conditions

- Post-merger outflow evolved with HARM-GRMHD by F. Nouri et al. 2023
- Outflow mapped in a large scale grid (setup of Mezcal-SRHD code)

**Tracers trajectory and angular distribution of mass**




**Post-merger engine parameters**

$a = 0.9$

$M_{\rm BH} = 2.65\, M_\odot$

$M_{\rm disk} = 0.10276\, M_\odot$

$t_{CE} \sim M_{\rm disk}/\dot{M}$

**Jet parameters**

$t_{\rm jet} = 1 \lesssim t_{CE}$

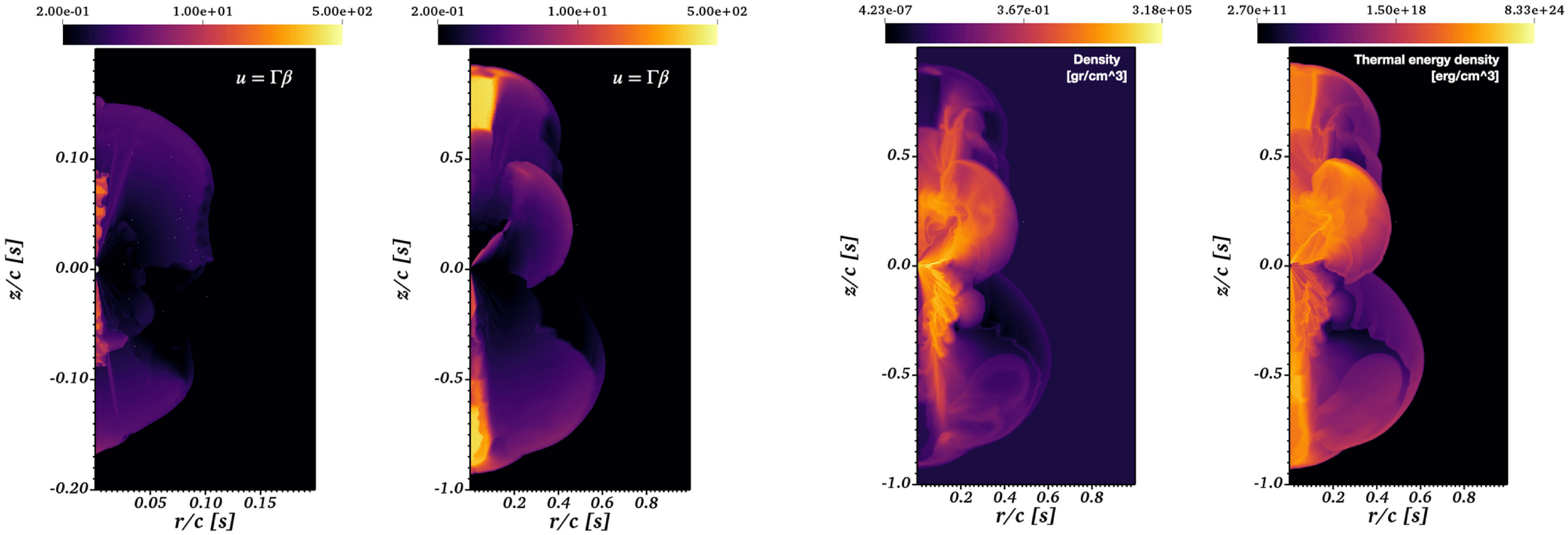
$L_{\rm jet} = 5 \times 10^{51}$ erg s$^{-1}$

$\theta_{\rm jet} \leq 0.1$ rad

$\Gamma_{\rm jet} = 3$

$\Gamma_\infty = 500$

# Large-Scale Simulations



# Main references


- **Mezcal Code:** De Colle, F. et al. (2012), ApJ 746 122.
- **HARM-COOL Code:** Janiuk, A. (2019), ApJ 882 163
- **Post merger outflows:** Nouri, F.H., Janiuk, A., and Przerwa, M. (2023), ApJ 944 220.
- **Large Scale SGRB implementation:** Urrutia, G., De Colle, F., Murguia-Berthier, A., and Ramirez-Ruiz, E. (2021), MNRAS 503 4363