EOS@FAIR

CONSTRAINING NEUTRON STAR MATTER WITH HEAVY ION COLLISIONS

Marcus Bleicher (bleicher@itp.uni-frankfurt.de)
Institut für Theoretische Physik
Goethe Universität Frankfurt
Germany

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

HFHF Helmholtz Forschungsakademie Hessen für FAIR

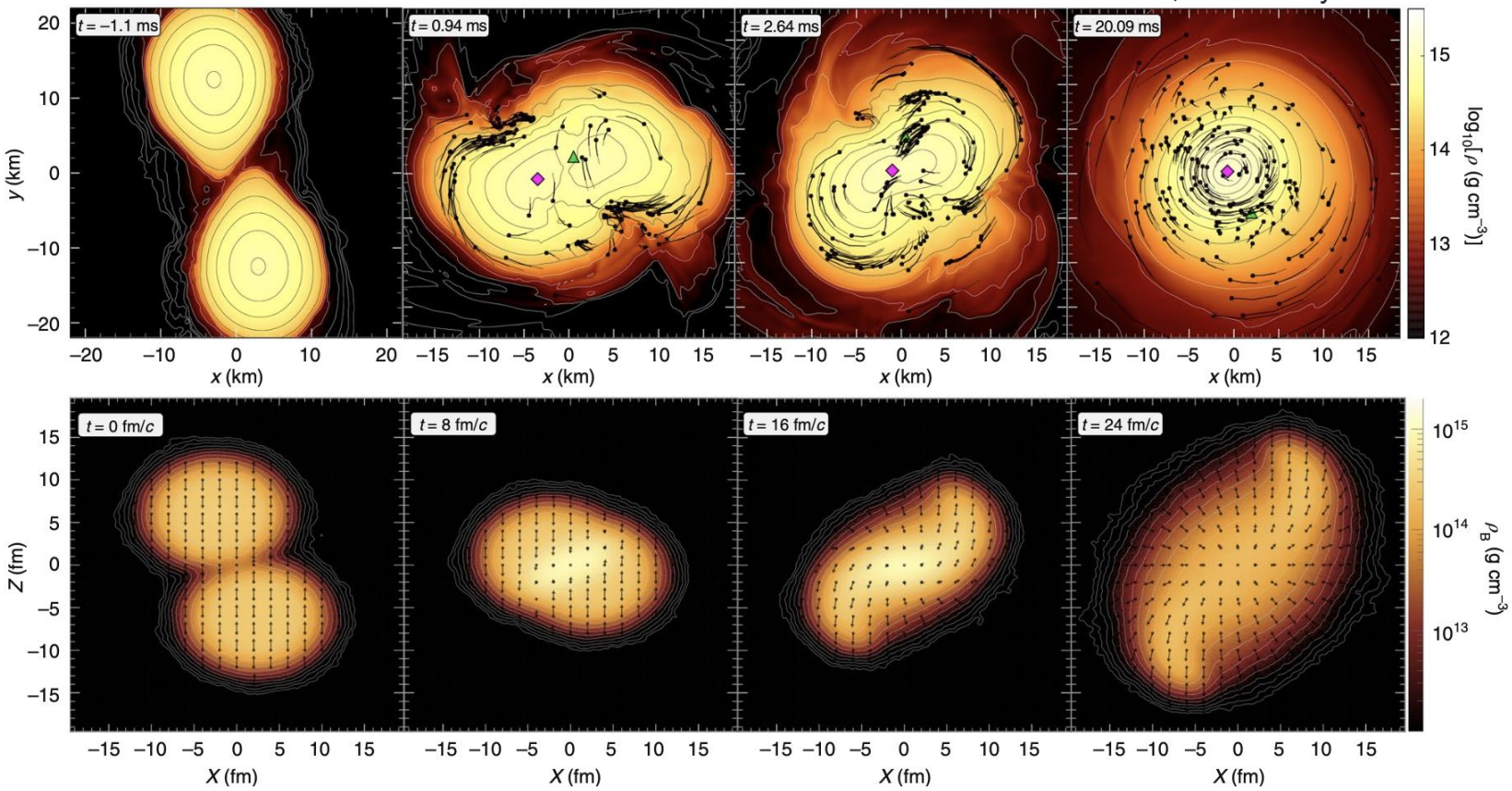
GSI

Neutron star mergers vs heavy ion collisions

Neutron Star merger

Heavy Ion collision

from HADES, Nature Physics 15

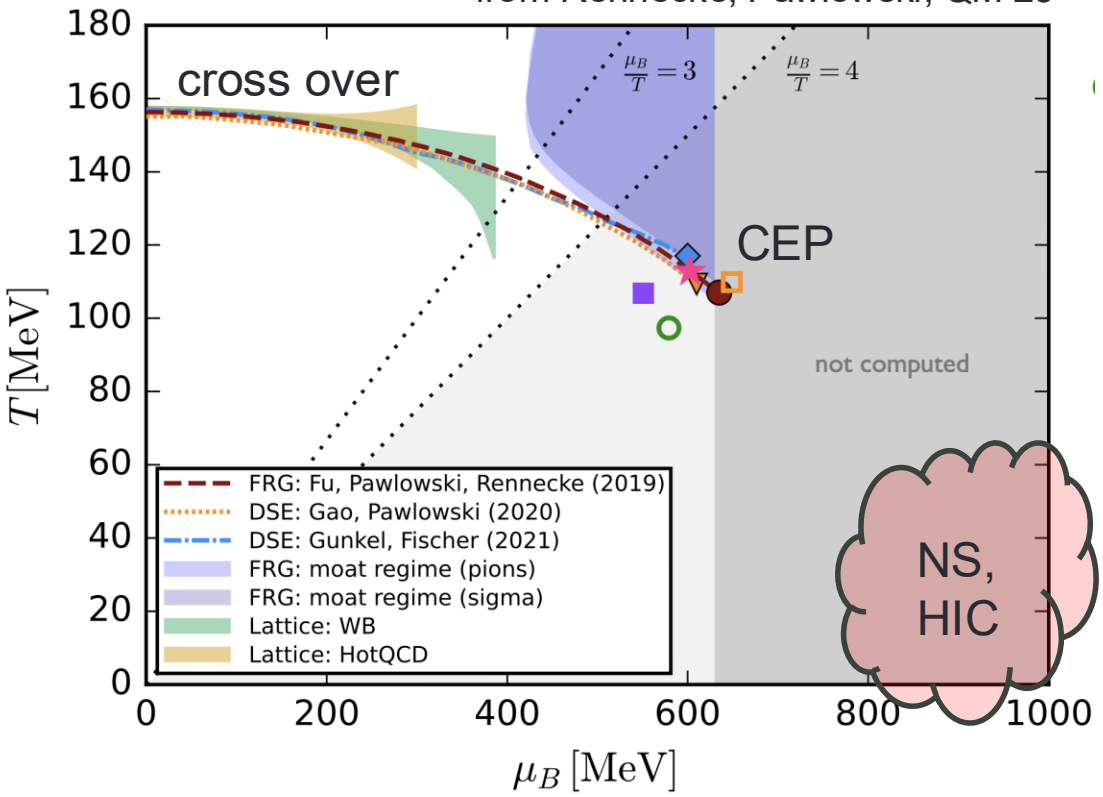


Both proceed in the same range of (low) temperature and (high) baryon density, **i.e. μ/T >> 1**

What do we know?

- lattice QCD data only at low μ/T
- FRG methods at moderate μ/T
- Neutron star matter and HIC not in reach
- At higher μ/T only phenomenological approaches exist

from Rennecke, Pawlowski, QM 25



→ QCD matter at highest μ/T is the central physics topic of CBM@FAIR

What do we need to know!

- Recent community effort (coordinated by A. Sorensen, FRIB) to identify the pressing questions about the **"Dense nuclear matter equation of state"**, *Prog.Part.Nucl.Phys.* 134 (2024), more than 100 authors

- Structure of the phase diagram (critical point? Quarkyonic?)
- Active degrees of freedom (partons?, hadrons?, hyperons?)
- Equation-of-State, Pressure (T, ρ_B) for high ρ_B
- Transport properties (viscosities, conductivities)

- Does it work for 1) Neutron Stars?
  2) Binary Neutron Star mergers?
  3) Heavy Ion collisions?

Who we bring together for answers.

- 1.) Structure of the QCD phase diagram, EoS and the CEP:
  Community from lattice QCD, functional methods (FRG, Dyson-Schwinger), and effective (chiral) models → provide information in equilibrium

- 2.) Development and unification of transport and hydrodynamic simulations:
  Community of phenomenologists and dynamical model builders, bridging from "fundamental" theory to experiments. Development, benchmarking, repositories, conventions,... → extend to non-equilibrium

Full breadth theoretical approach, bringing together different communities

- 3.) Predictions for measurements:
  Community of experimental and phenomenological heavy ion and astrophysicists. Concrete predictions for experiments at GSI/FAIR, analysis and interpretation of existing and new data from RHIC-BES and CERN/NA61, transfer/feedback to/from astrophysics community → obtain consistent EoS

Connecting theoreticians and experimentalists

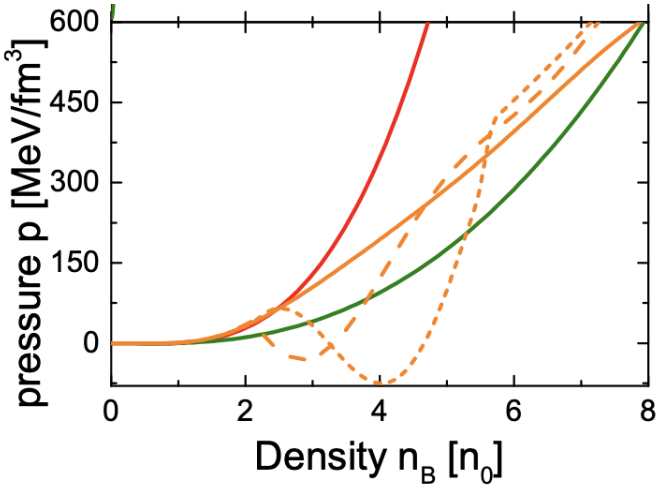
Typical knowledge chain

lQCD (μ/T<2)
FRG (2<μ/T<5)

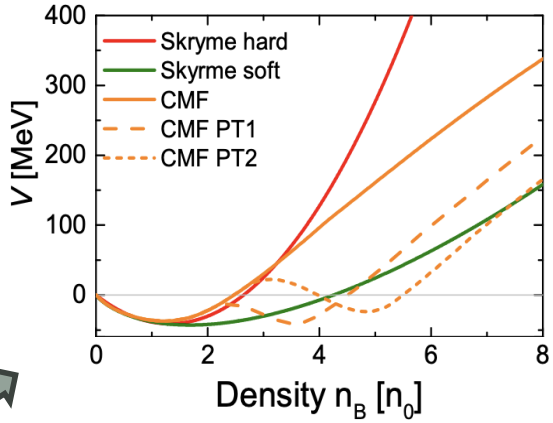
fix params

Chiral EFT
(μ/T>5)

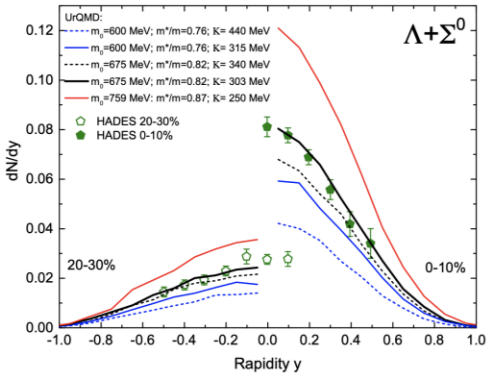
get EoS



create a potential,
in-medium properties,... for dynamical model

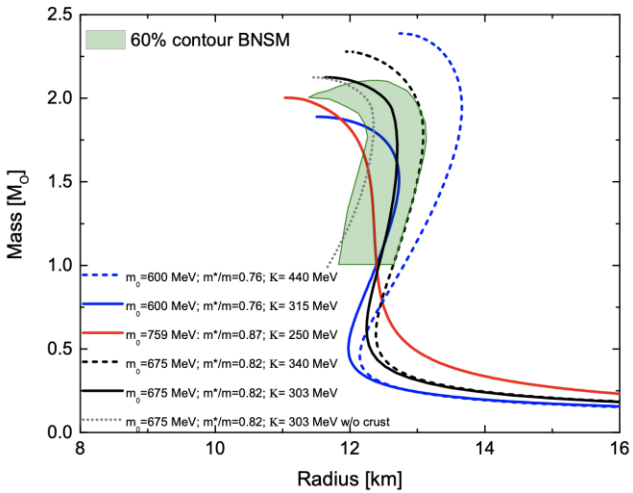


compare to data
learn if it works



constrain
high μ/T part

predict NS



all figs. from Steinheimer et al.

Relevance for the Infrastructures

QCD matter at highest μ/T is the central physics topic of CBM@FAIR

- Focus on GSI/FAIR,
  - inclusion of RHIC-BES and CERN/NA61 community

- Improve the quality of the research at GSI/FAIR (BNL, CERN) by providing specific predictions and necessary model development relevant for the interpretation of the data

- Providing cross-disciplinary fertilisations and a wider sharing of information, knowledge and technologies across these scientific fields by closer interactions between researchers active in and around the GSI/FAIR, BNL and CERN research infrastructures

Participating institutions

1. Florence University, Italy
2. Wroclaw University, Poland
3. Goethe University, Germany
4. GSI Helmholtz Center, Germany
5. Justus-Liebig University, Germany
6. Berg. Univ. Wuppertal, Germany
7. Univ. Heidelberg, Germany
8. University Claude Bernard, France
9. CTU, Czech Republic
10. INFN Florence, Italy
11. ICE, Barcelona, Spain
12. U Banska Bystrica, Slovakia
13. Wigner Research Center, Hungary
14. SUBATECH, France

Requests from outside EU:

- Selcuk University, Turkey
- Fudan University (Shanghai), China
- Huzhou University (Huzhou), China
- Akita International University, Japan
- LBNL, Berkeley, USA
- Duke University, USA

Budget estimate

- Organization of an annual expert workshop and support for travel
(400€ travel/pax, 6 nights (100€/night/pax) * 30 participants → 30.000 € p.a.
- Training activities for ECRs, incl. travel and accommodation
(400€ travel/pax, 6 nights (100€/night/pax) * 5 lecturers +20 ECR → 25.000 € p.a.
- Outreach and science communication activities (Website/public talks) → 5.000 € p.a.
- Indirect costs (management/overhead) → 15.000 € p.a.
- Total cost: 4 years x 75.000 € /year = 300.000 €