
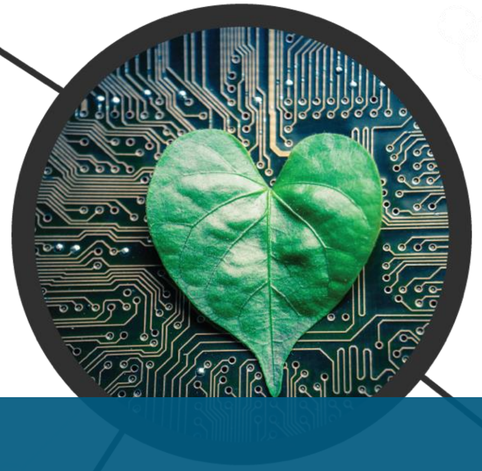
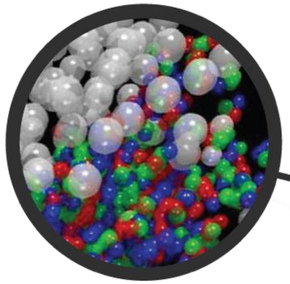


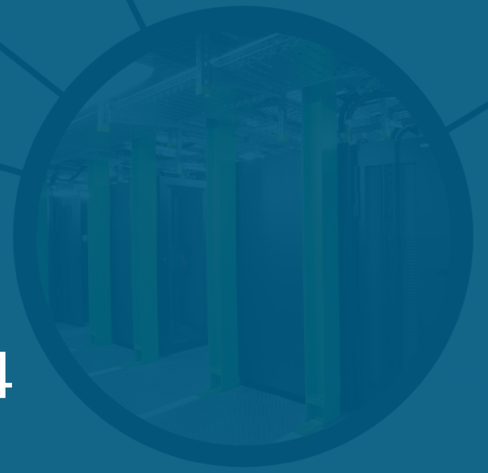
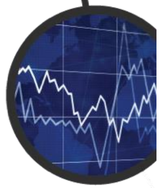

Physics@FIAS

L. Rezzolla

FIAS Scientific Advisory Board, 13.-14.3.2024

Four main research areas






- **Dense nuclear matter**
  - Heavy ion collisions (HIC),
  - equation of state (EOS) of nuclear matter

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  - Gravitational waves and multi-messenger astrophysics
  - Supermassive Black Holes




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  - Alternative theories, BH alternatives




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  - Gravitational waves and multi-messenger astrophysics
  - Supermassive Black Holes


- **Gravitation Theory**
  - Alternative theories, BH alternatives
- **Physical Applications of ML and AI**
  - EOS, energy networks, seismology, etc.



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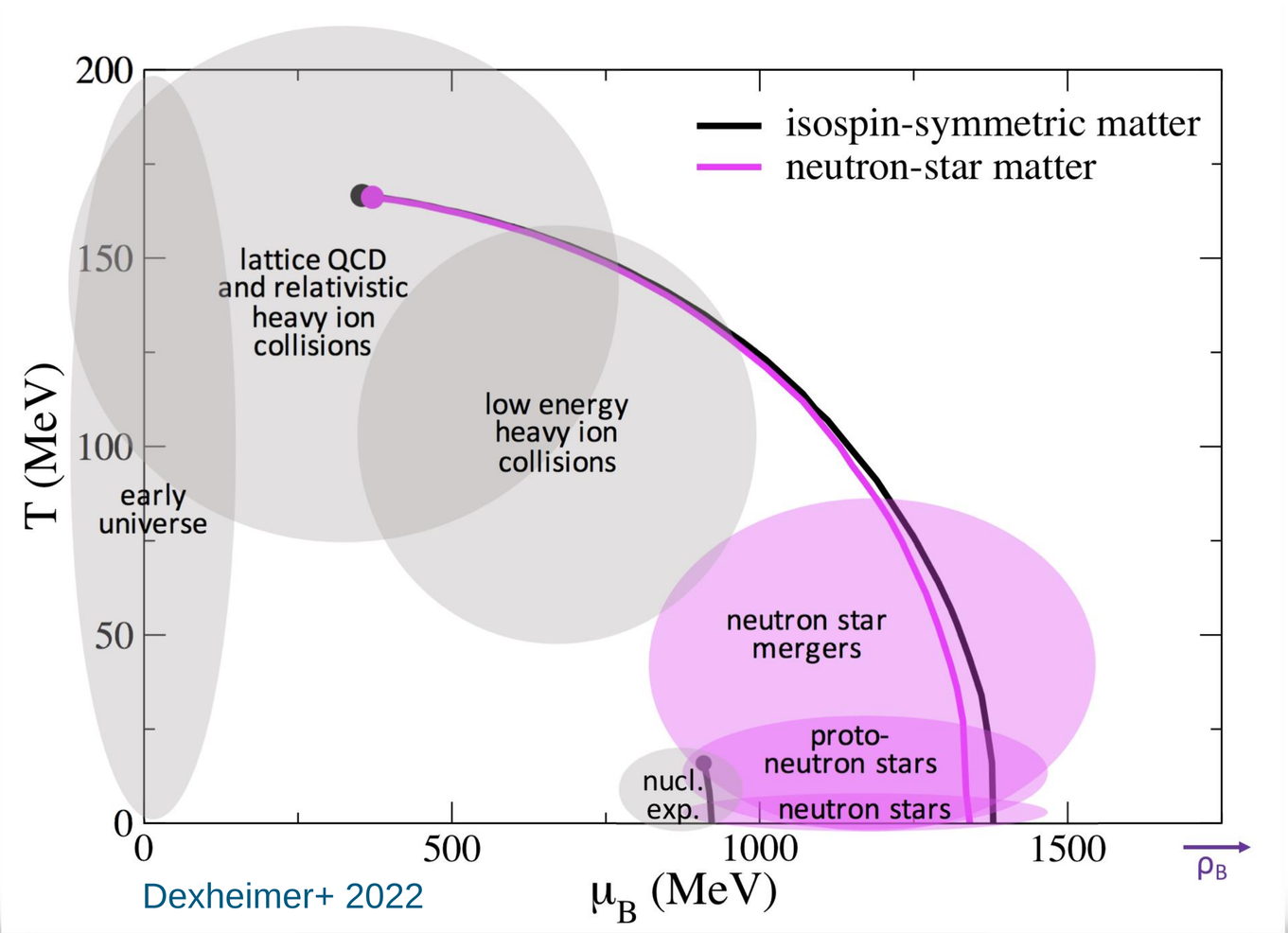
Dense nuclear matter



Dexheimer+ 2022

The QCD Phase diagram is the physical map of our understanding of the basic laws of matter from the early universe to our daily environment.

Different tools are used to explore this diagram in different regions.

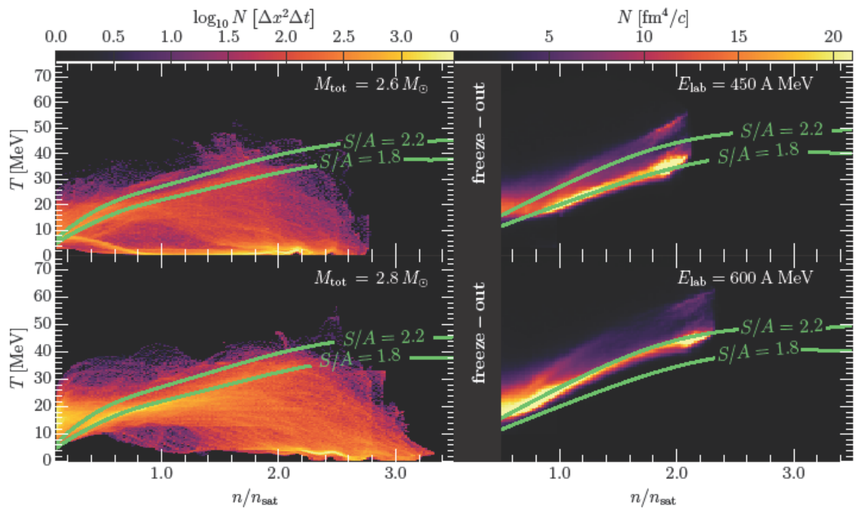
Billion-euro experiments are built across the planet to explore the physics of **heavy-ion collisions**

Gravitational-wave detectors and satellites are being employed to study **neutron stars.** Novel **gateway** to new **physics** and **astrophysics**

Dense nuclear matter

Heavy Ion Collisions (HIC) and neutron star mergers (BNSM) can be described on the same EOS.

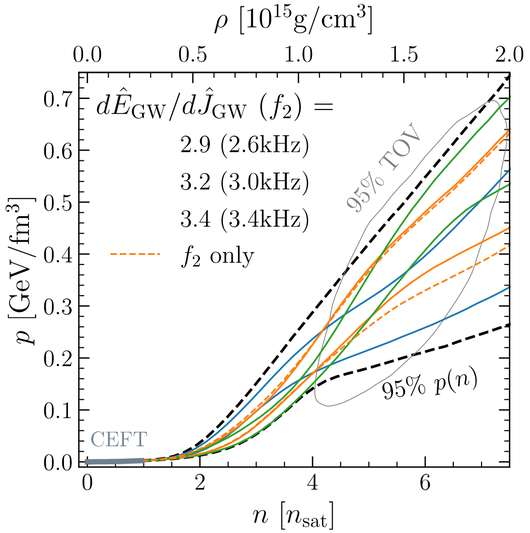
BNSM **HIC**

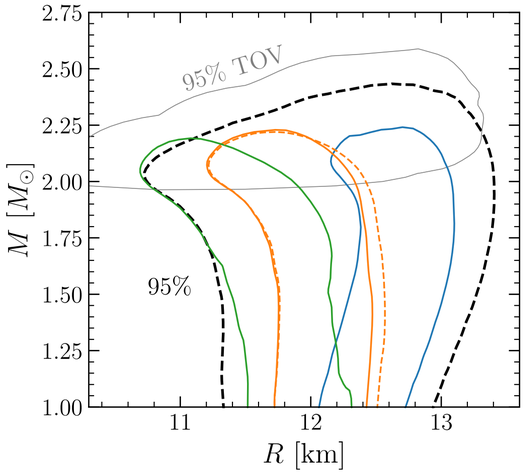


E. R. Most, A. Motornenko, J. Steinheimer, V. Dexheimer, M. Hanauske, L. Rezzolla and H. Stoecker, Phys. Rev. D 107, no.4, 043034 (2023).

Transport models developed at FIAS can now be used for statistic inference of the EOS in HIC. Bayesian inference of the nuclear EOS featured on title page of PRL

M. Omana Kuttan, J. Steinheimer, K. Zhou and H. Stoecker, Phys. Rev. Lett. 131, no.20, 202303 (2023)





Novel feature in post-merger GW signal allows to set new and unprecedent constraints on the EOS of nuclear matter

C. Ecker, T. Gorda, A. Kurkela, L. Rezzolla, Nature (submitted) 2024

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Gravitation and astrophysics: next generation of detectors

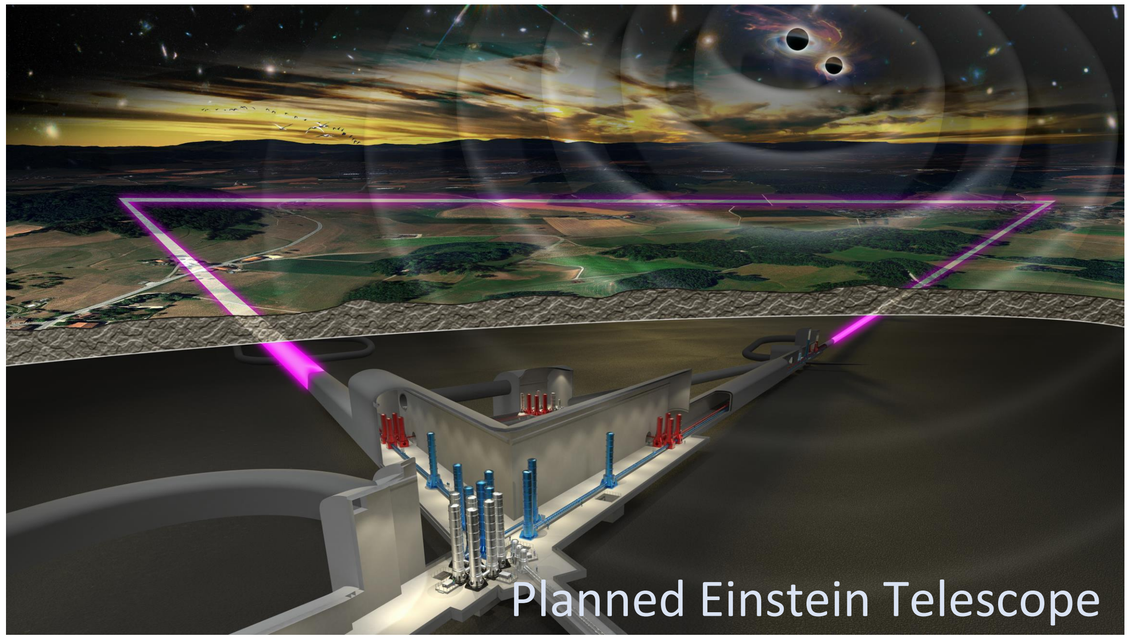

Virgo, Cascina, Italy


LIGO, Livingston, LA


LIGO, Hanford, WA

These detectors have provided numerous scientific breakthroughs with events such as **GW150914** or **GW170817**

They are presently taking data and a final O5 data-taking run is expected to go past **2028**.


Planned Einstein Telescope

- Large laboratories and three 10 km long tunnels, more than 200m underground.
- 10 times better than design sensitivity of current detectors, providing GW data for astronomy and fundamental physics for at least 50 years.
- Possible locations: i) Meuse-Rhine Euroregion site, close to the NL-B-D border, ii) Sardinia and iii) Saxony (??), D

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Gravitation and astrophysics: next generation of detectors

ASTROPHYSICS

Black hole properties
- origin (stellar vs. primordial)
- evolution, demography

Neutron star properties
- interior structure (QCD at ultra-high densities, exotic states of matter)
- demography

Multi-band and -messenger astronomy
- joint GW/EM observations (GRB, kilonova,...)
- multiband GW detection (with LISA)
- neutrinos

Detection of new astrophysical sources
- core collapse supernovae
- isolated neutron stars
- stochastic background of astrophysical origin

FUNDAMENTAL PHYSICS AND COSMOLOGY

The nature of compact objects
- near-horizon physics
- tests of no-hair theorem
- exotic compact objects

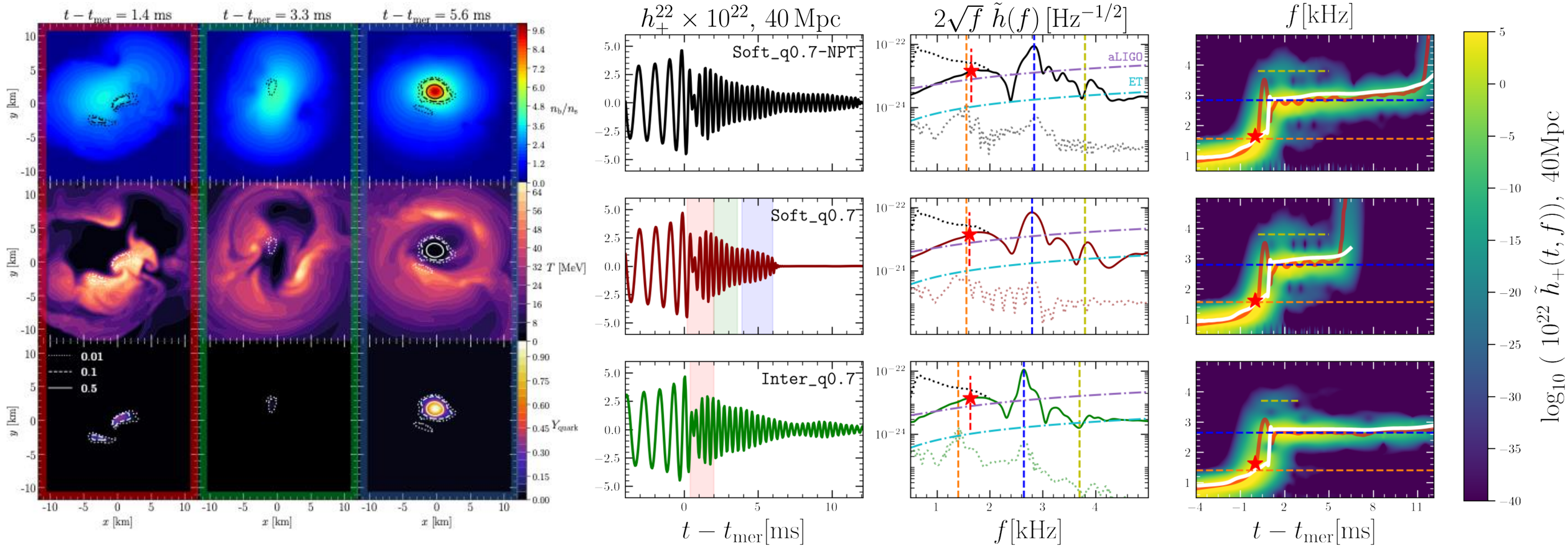
Tests of General Relativity
- post-Newtonian expansion
- strong field regime

Dark matter
- primordial BHs
- axion clouds, dark matter on compact objects

Dark energy and modifications of gravity
- dark energy equation of state
- modified GW propagation

Stochastic backgrounds of cosmological origin
- inflation, phase transitions, cosmic strings

Gravitation and astrophysics: nuclear astrophysics



Simulations in full general relativity allow us to explore the QCD phase diagrams and assess the gravitational-wave signatures of phase transition from hadron to quark matter

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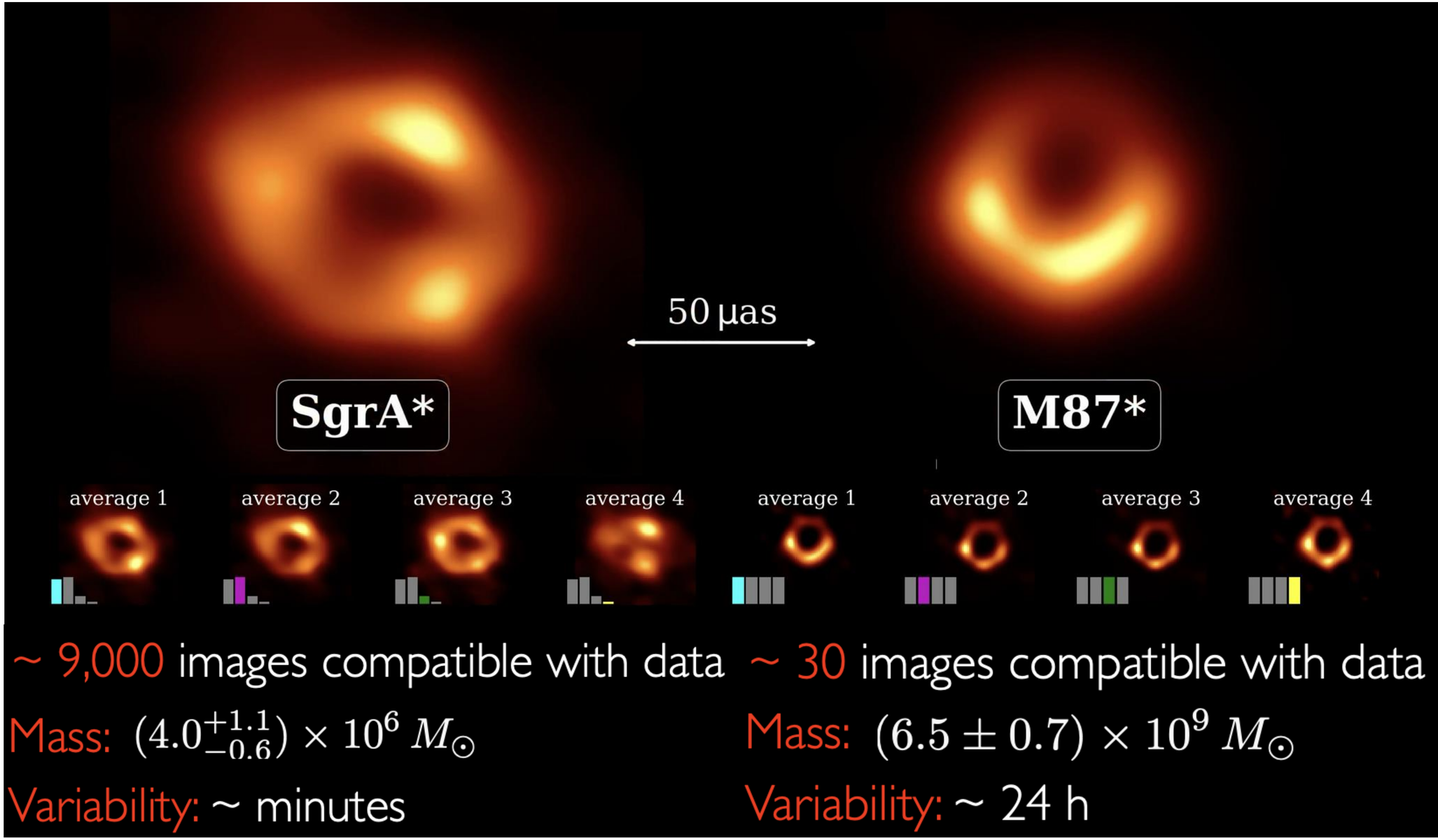
Gravitation and astrophysics: SMBHs

FIAS contributing to imaging of super-massive black holes by Event Horizon Telescope (EHT)

Good part of theory work of EHT is carried out in Frankfurt.



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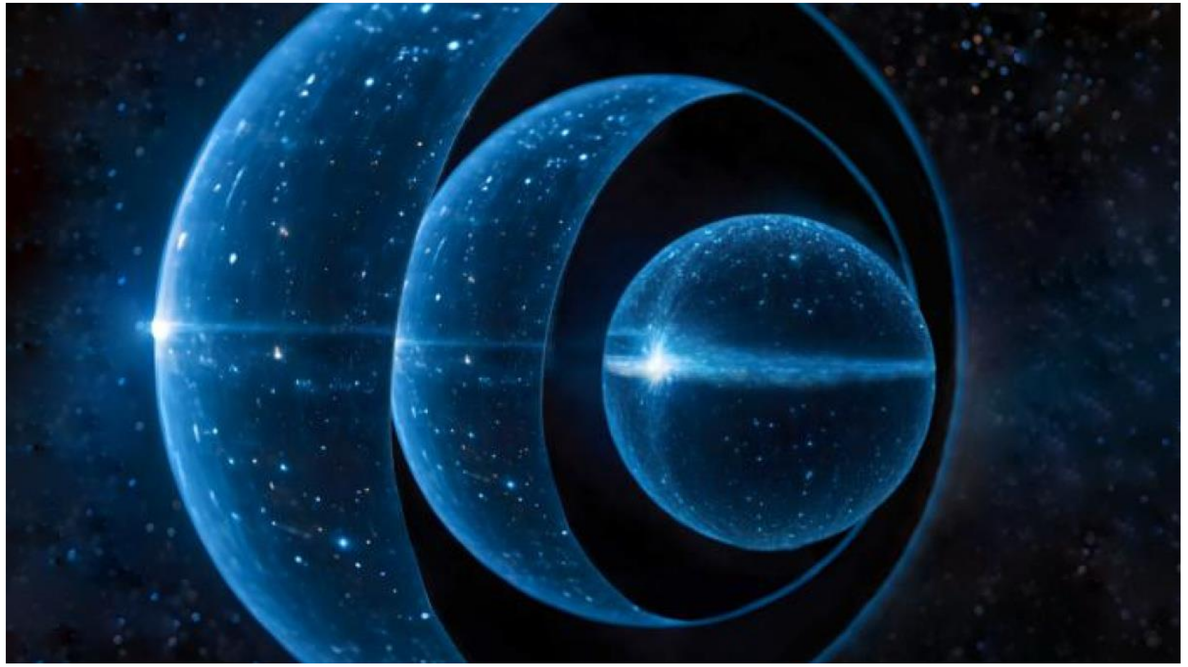
Gravitation Theory

Spacetime with Inertia and Torsion	Singularity Theorems	Cosmology and MCMC Analysis
Torsion Waves, Massive Torsion Modes	Torsional Dark Energy	Covariant Canonical Quantization



Theoretical aspects are explored within Gauge Theories of gravity starting from Action Principle to obtain full spectrum of theories including torsion.

New solutions of “black-hole mimickers” studied to better understand black hole. Recent “***nestar***” solution attracted lot of attention public/not (300K views on Youtube)

D. Jampolski, L. Rezzolla, CQG (2024)

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Physical Applications of AI

Over last few years FIAS has applied ML and DL to variety of scenarios

- QCD diagram and QFT
- Heavy ion collisions
- NS and gravitational-wave emission
- Energy distribution networks
- Epidemiology
- Lightning occurrence and statistics
- THz imaging

Nishthas Srivastava,
Kai Zhou,
Jan Steinheimer,
Markus Schlott
Horst Stoecker

Thank you