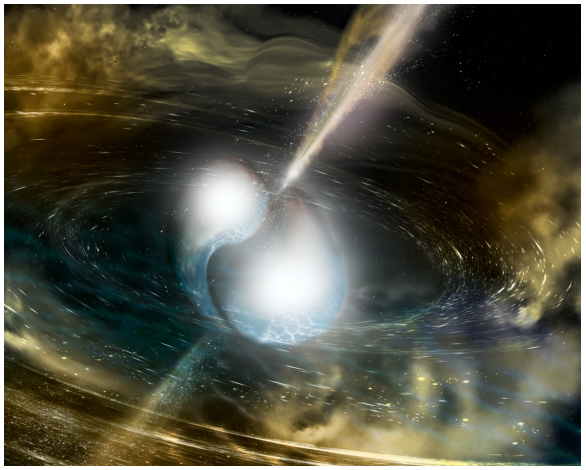


Gravitational wave data analysis

Chris Van Den Broeck

Nikhef

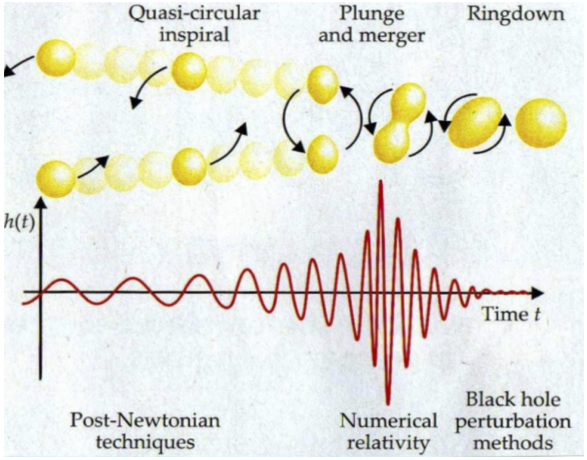
LIGO VIRGO

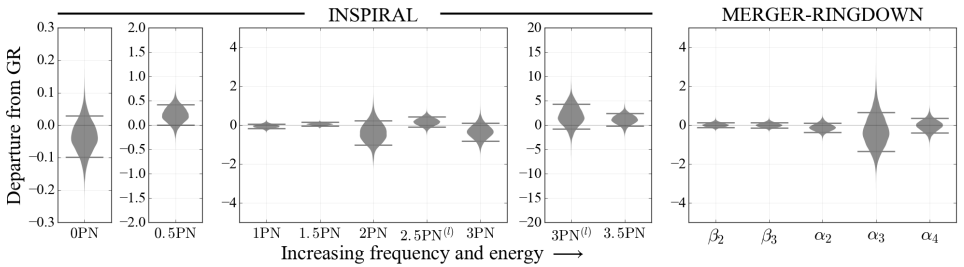
Universiteit Utrecht

Nikhef SAC, 13-04-2023

Testing general relativity and the nature of compact objects

- Testing the dynamics of binary black hole coalescence:





  - Higher harmonics of the basic signal:
    Are the amplitudes consistent with GR?

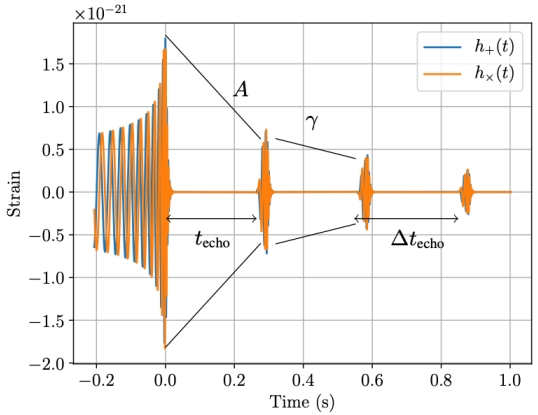
Puecher et al., PRD **106** , 082003 (2022)

- Looking for anomalous propagation of gravitational waves
  - E.g. due to a non-zero graviton mass
    Current bound: $m_g \leq 1.76 \times 10^{-23}\,\mathrm{eV}/c^2$

LIGO, Virgo, KAGRA, arXiv:2112.06861

- Black holes, or black hole mimickers?
  - Search for gravitational wave echoes emitted by horizonless objects

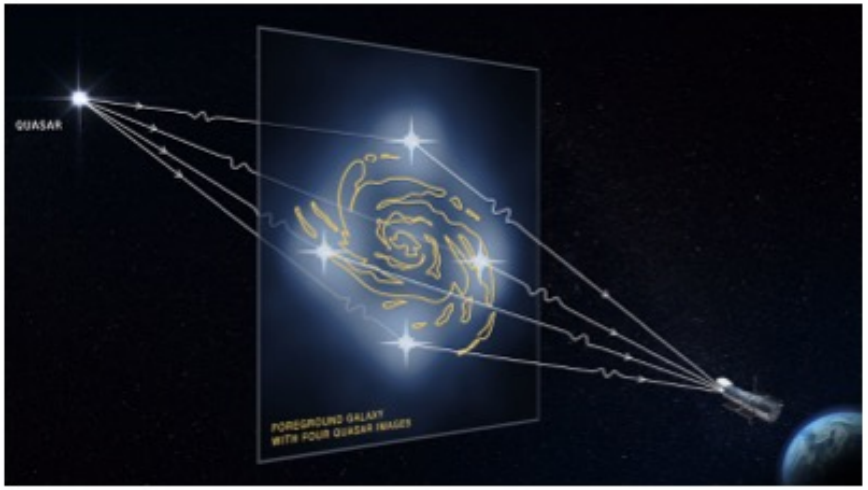
Tsang et al., PRD **101**, 064012 (2020)
LIGO, Virgo, KAGRA, arXiv:2112.06861

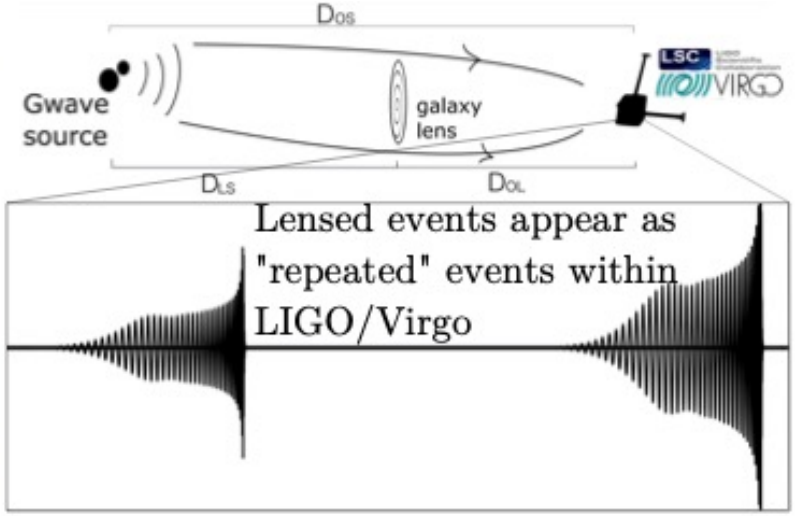


Lo et al., PRD **99**, 084052 (2019)

Lensing of gravitational waves

- Just like light, gravitational waves can undergo lensing



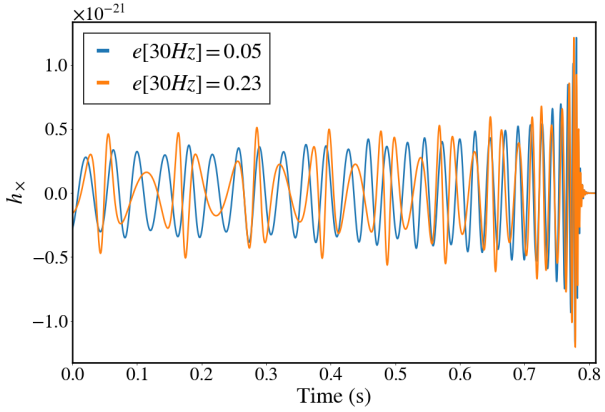


- Gravitational wave images:
  - Copies of the original signal, but (de)magnified
  - Arriving at different times: minutes to months apart
  - Expected to be discovered in coming years

- Difficult to search for:
  - Developed an efficient way to check all pairs of detected signals for similarities
    Janquart et al., MNRAS **506**, 5430 (2021)
  - Use of lens models to keep false alarm probability under control
    Wierda et al., Astrophys. J. **921**, 154 (2021)
    Janquart et al., MNRAS **519**, 2046 (2022)

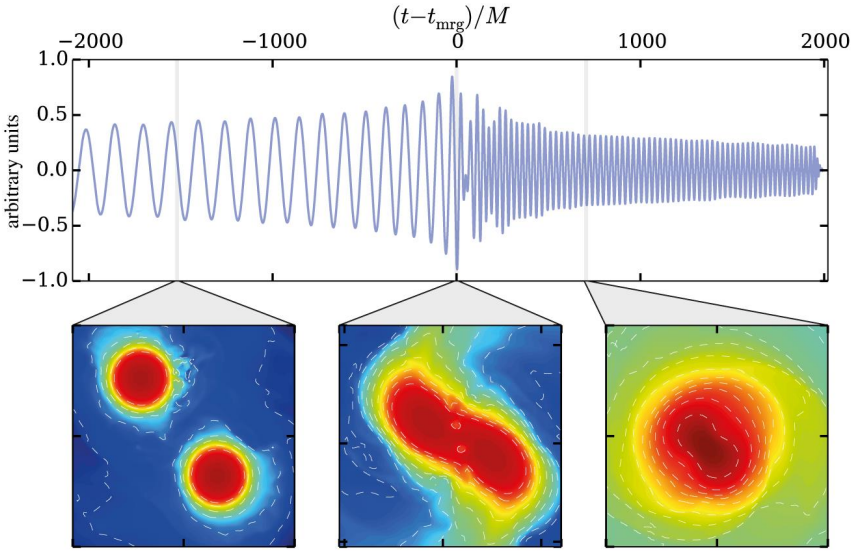
Waveform modeling

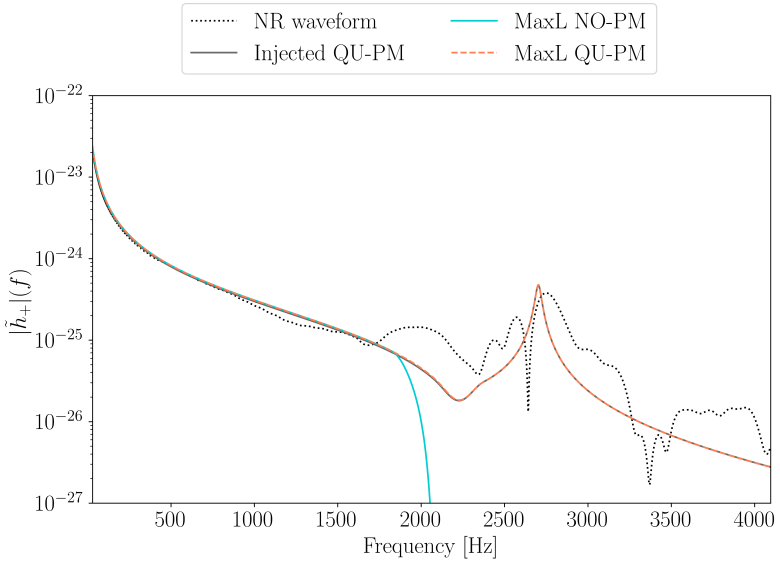
- Effect of eccentric orbits on binary black hole waveforms



Ramos-Buades, Tiwari, Haney, et al.,
PRD **102**, 043005 (2020)

- Phenomenological models for binary neutron star inspiral-merger-postmerger

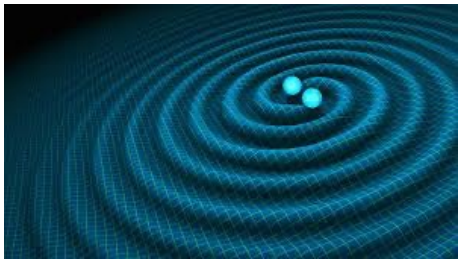




Puecher et al., arXiv:2210.09259

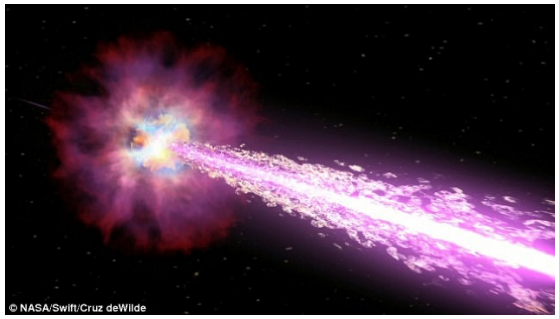
The equation of state of dense nuclear matter

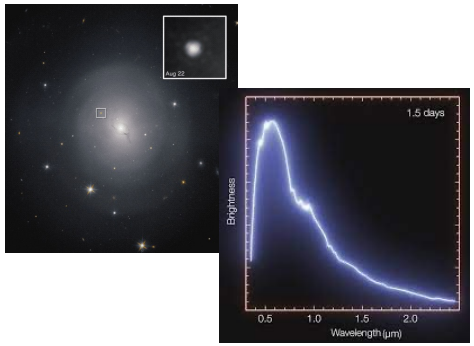
Empirical channels:



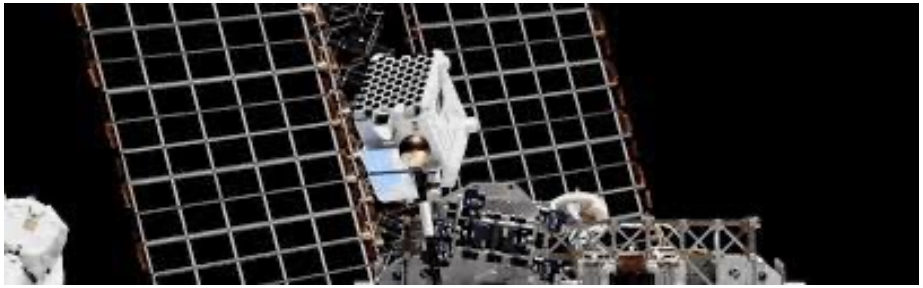
- GW observations of binary neutron star coalescences

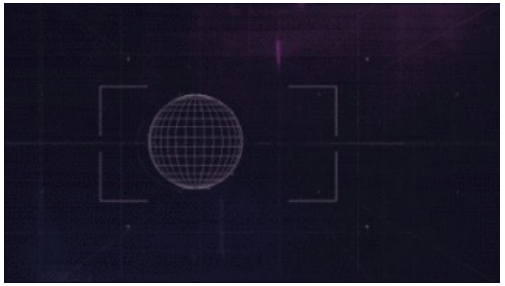
- Electromagnetic counterparts: jet and afterglow





- Mass-radius measurements on pulsars with the Neutron Star Interior Composition Explorer (NICER)

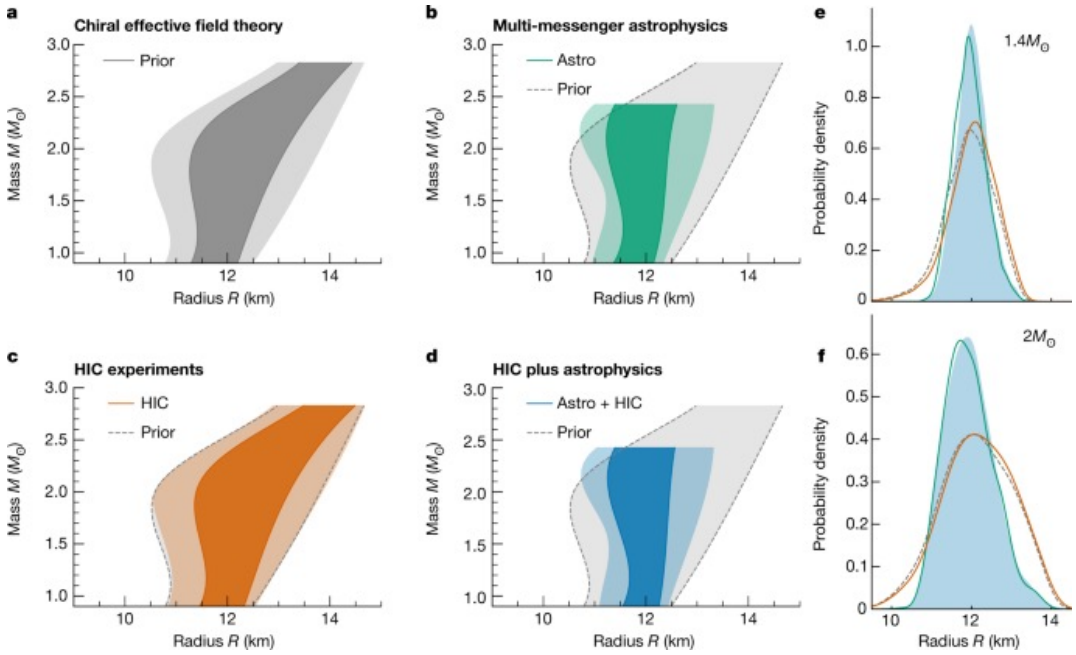




- **Heavy ion collisions in accelerators on Earth**

The equation of state of dense nuclear matter

Unified Bayesian data analysis framework to combine information from all these channels:



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Constraining neutron-star matter with microscopic and macroscopic collisions

Sabrina Huth, Peter T. H. Pang, Ingo Tews, Tim Dietrich, Arnaud Le Fèvre, Achim Schwenk, Wolfgang Trautmann, Kshitij Agarwal, Mattia Bulla, Michael W. Coughlin & Chris Van Den Broeck

Nature **606**, 276–280 (2022) | Cite this article

Huth et al., Nature **606**, 274 (2022)

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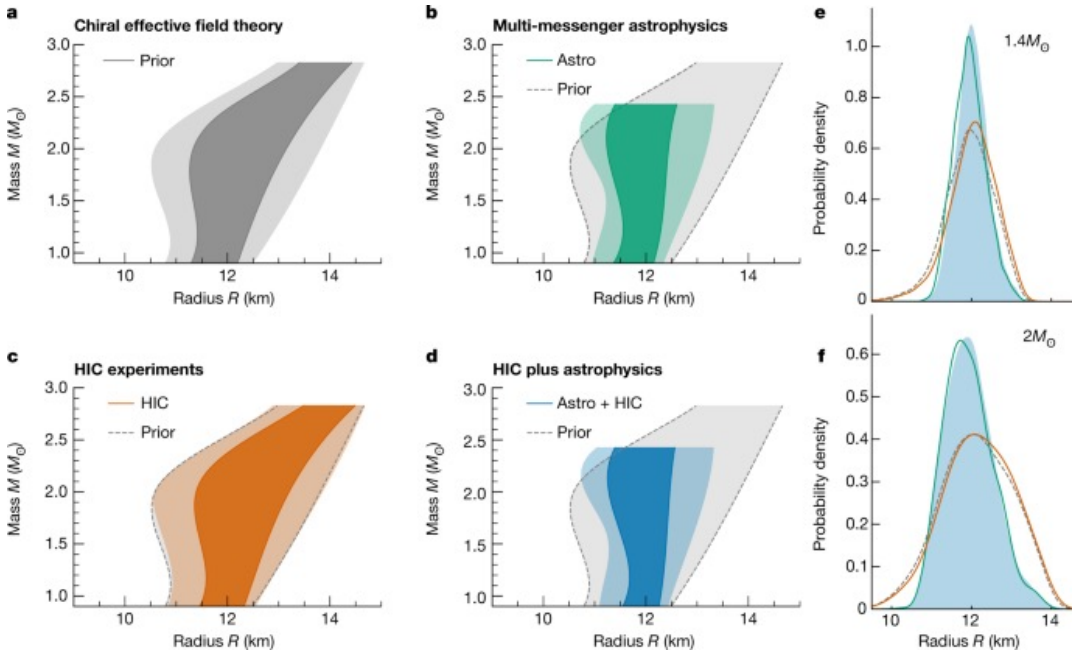

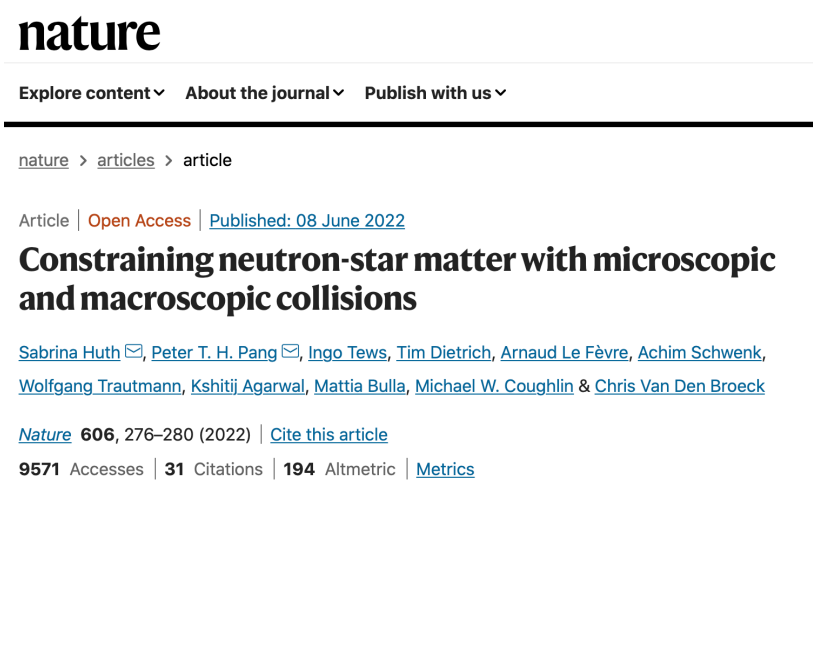

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Huth et al., Nature **606**, 274 (2022)

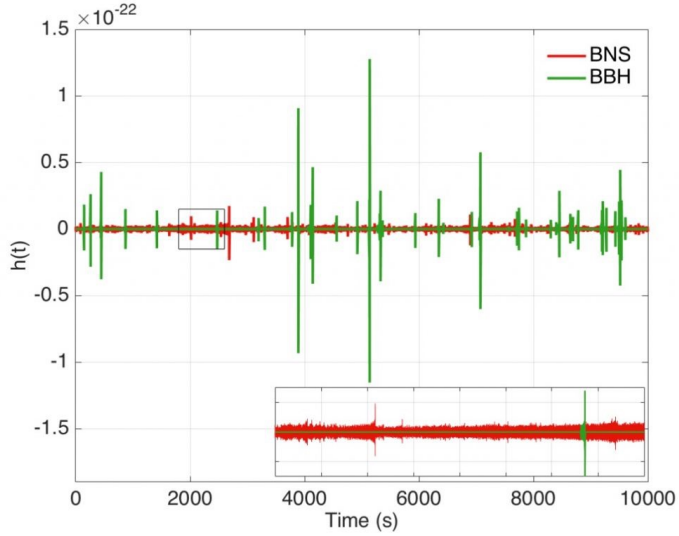
Can we connect with LHC physics? (ALICE)

- To be investigated through the grant “Probing the QCD phase diagram”

Towards Einstein Telescope

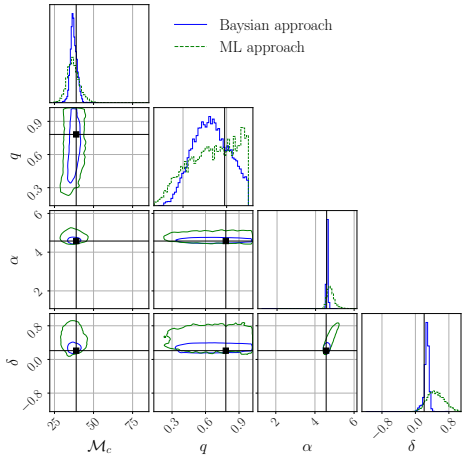
Einstein Telescope data analysis poses serious challenges:

- Loud signals, long signals, overlapping signals: "Traditional" search and parameter estimation techniques are inadequate



LIGO, Virgo, PRL **120**, 091101 (2018)

- Pursuing three avenues to address the parameter estimation problem:
  - Hierarchical subtraction of signals
  - Joint parameter estimation
  - Machine learning



- Will investigate how this carries over to LISA

Langendorff et al., arXiv:2211.15097
(accepted by PRL)