Decihertz GW Astronomy

Jan Harms

Gran Sasso Science Institute
INFN National Labs of Gran Sasso

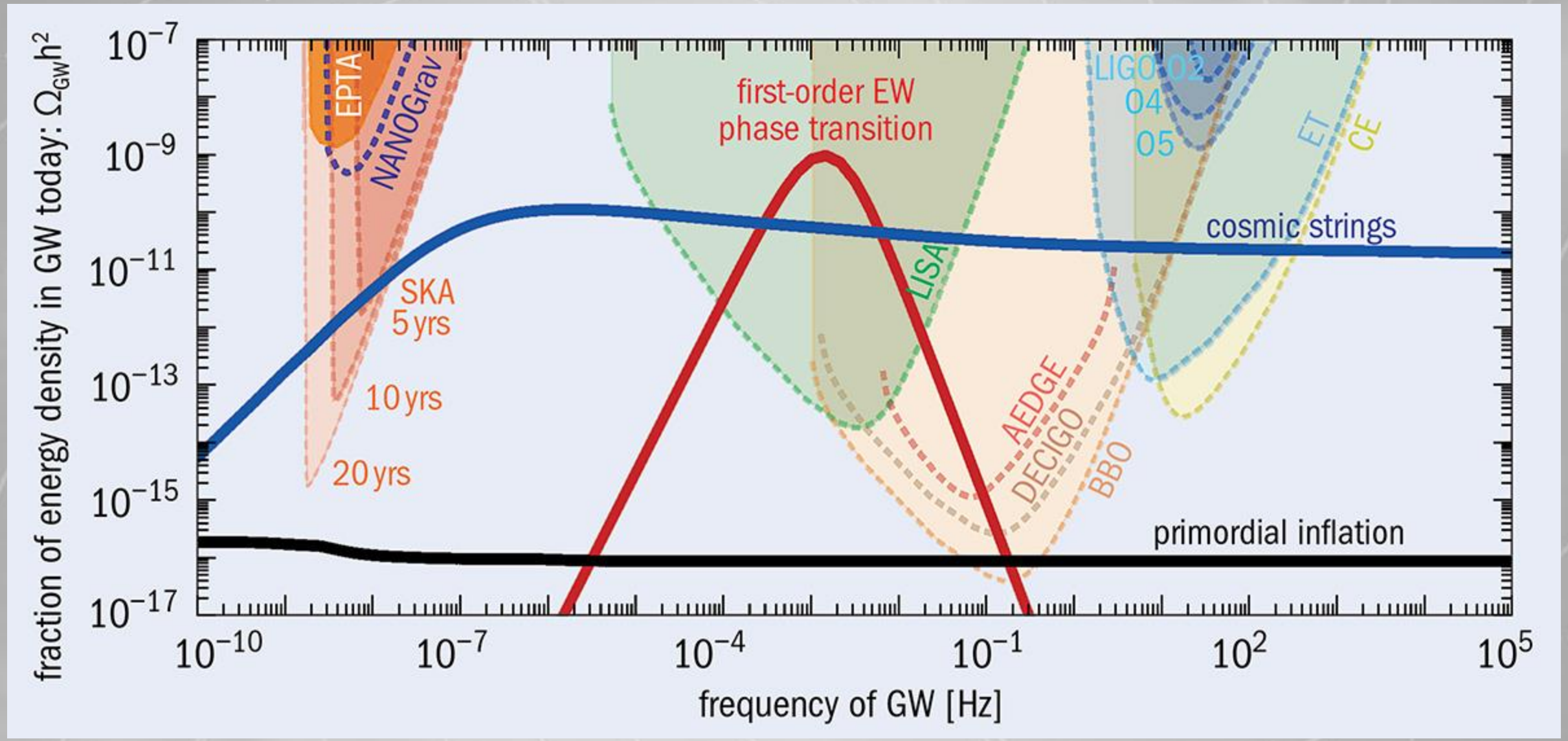
Big Bang Observer: The Birth of dHz GW Science

Science of the Big Bang Observer

Phinney et al (2003), Cutler/Harms (2006), Cutler/Holz (2009):

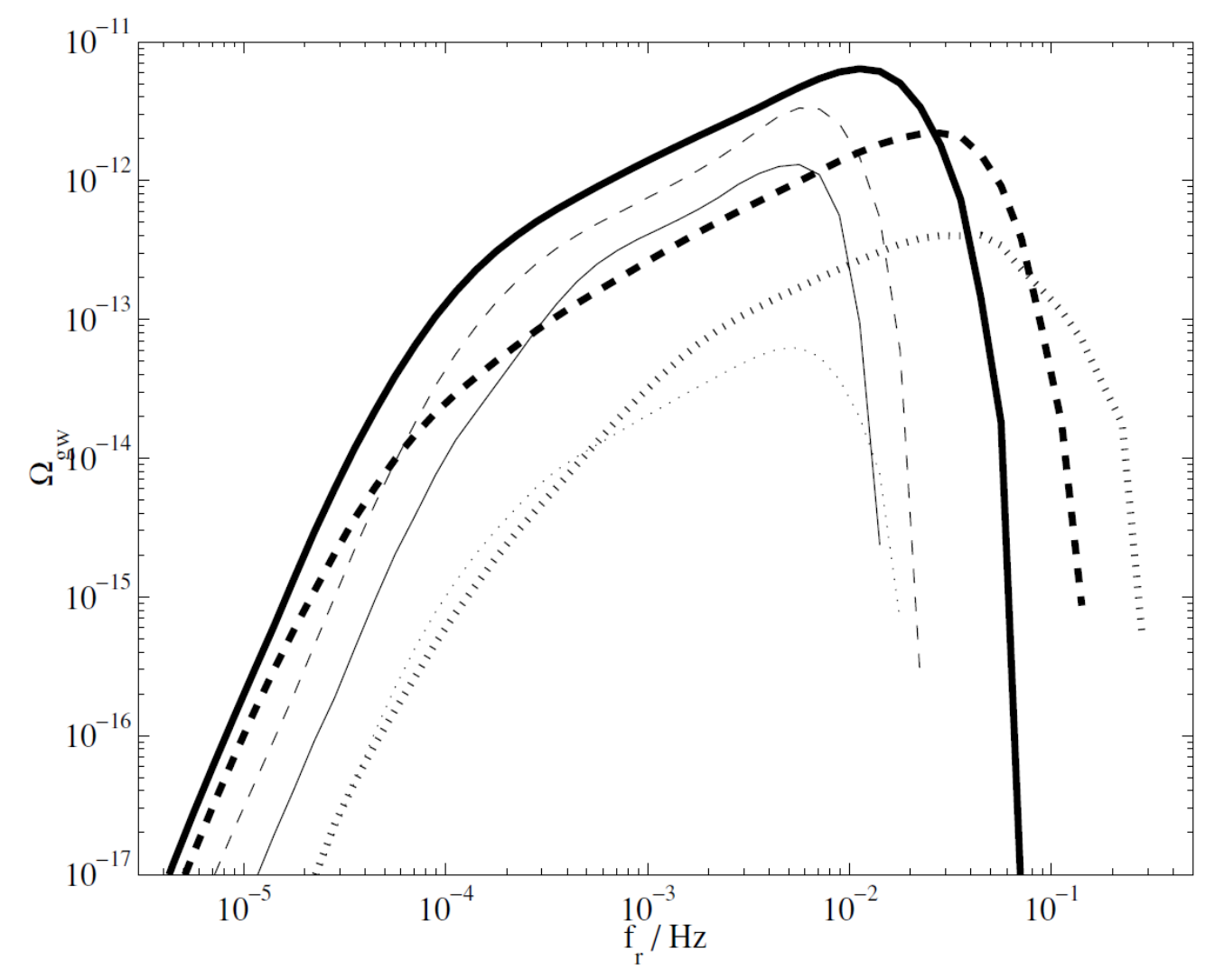
- Detection of a primordial background (even from slow-roll inflation)
- Detection (and their subtraction from data) of essentially all compact binaries composed of neutron stars and black holes
- Dark matter distribution via weak-lensing measurements
- Detection of a large number of double white dwarfs
- Hubble-constant measurement
- BNS pre-merger warning

Detection of a Primordial GW Background



P Simakachorn

Background of Double White Dwarfs



Farmer and Phinney (2003): The background of double white dwarfs peaks in the LISA band and then falls rapidly towards higher frequencies.

Conclusion:
Primordial GW background best observed in the decihertz band.

dHz GW Detector Concepts

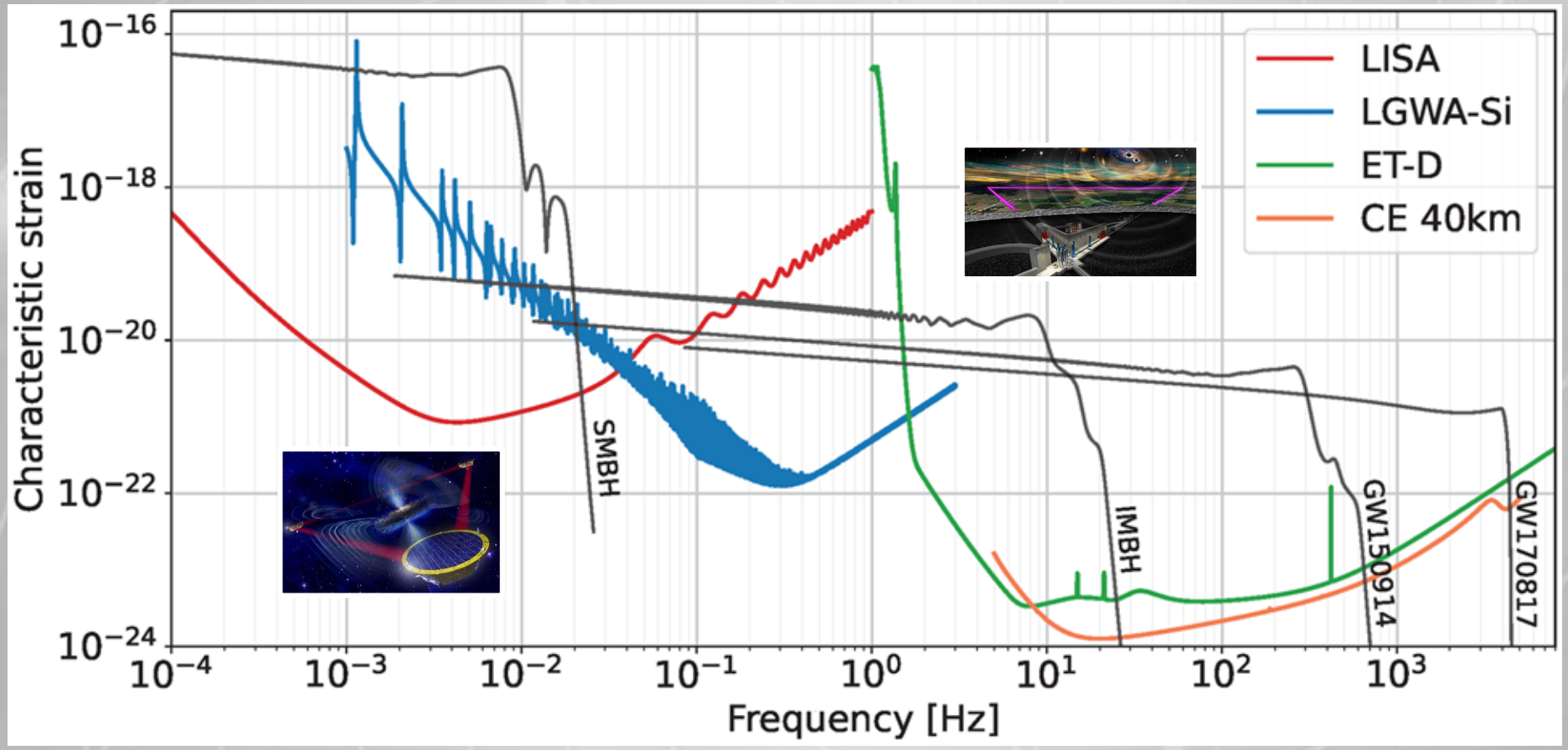
- Satellite based, long-baseline, solid test masses
- Satellite based, long-baseline, atom clocks or atom interferometers
- Lunar GW detectors

“Exotic” technologies

- Frequency-comb detectors
- Diamond detectors
- Superfluid helium

Show-stopped due to environmental noise:
Terrestrial decihertz GW detectors

Observation Bands / Multi-banding



LGWA Science White Paper

The Lunar Gravitational-wave Antenna: Mission Studies and Science Case JCAP01(2025)108

Parameswaran Ajith [60] Pau Amaro Seoane [36,37,38] Manuel Arca Sedda [1,2,15] Riccardo Arcodia [4] Francesca Badaracco [13,14] Biswajit Banerjee [1,2] Enis Belgacem [5,6] Giovanni Benetti[71] Stefano Benetti [37] Alexey Bobrick [54] Alessandro Bonforte [43] Elisa Bortolas [9,10] Valentina Braito [23,55] Marica Branchesi [1,2,15] Adam Burrows [65] Enrico Cappellaro [37] Roberto Della Ceca [23] Chandrachur Chakraborty [61] Shreevathsa Chalathadka Subrahmanya [49] Michael W. Coughlin [3] Stefano Covino [23] Andrea Derdzinski[47,48] Aayushi Doshi [56] Maurizio Falanga [29,30] Stefano Foffa [5,6] Alessia Franchini [40,9,10] Alessandro Frigeri [27] Yoshifumi Futaana [51] Oliver Gerberding [49] Kiranjyot Gill [66] Matteo Di Giovanni [7,8] Ines Francesca Giudice[67,68] Margherita Giustini [12] Philipp Gläser [53] Jan Harms[1] [1,2] Joris van Heijningen [45,46] Francesco Iacovelli [5,6] Bradley J. Kavanagh [24] Taichi Kawamura [50] Arun Kenath [22] Elisabeth-Adelheid Keppler [18] Chiaki Kobayashi [64] Goro Komatsu [44] Valeriya Korol [32] N. V. Krishnendu [60] Prayush Kumar [60] Francesco Longo [18,19] Michele Maggiore [5,6] Michele Mancarella [9,10,11] Andrea Maselli [1,2] Alessandra Mastrobuono-Battisti [28] Francesco Mazzarini [39] Andrea Melandri [16] Daniele Melini [38] Sabrina Menina [41] Giovanni Miniutti [12] Deeshani Mitra [58] Javier Morán-Fraile [33] Suvodip Mukherjee [31] Niccolò Muttoni [5,6] Marco Olivieri [17,27] Francesca Onori [15] Maria Alessandra Papa [63] Ferdinando Patat [42] Andrea Perali [69,70] Tsvi Piran [59] Silvia Piranomonte [16] Alberto Roper Pol [5,6] Masroor C. Pookkillath [62] R. Prasad [60] Vaishak Prasad [60] Alessandra De Rosa [27] Sourav Roy Chowdhury [34,35] Roberto Serafinelli [16] Alberto Sesana [9,10,23] Paola Severgnini [23] Angela Stallone [17] Jacopo Tissino [1,2] Hrvoje Tkalčić [52] Lina Tomasella [37] Martina Toscani [9] David Vartanyan [57] Cristian Vignali [25,26] Lucia Zaccarelli [17] Morgane Zeoli [20,21] Luciano Zuccarello [39]

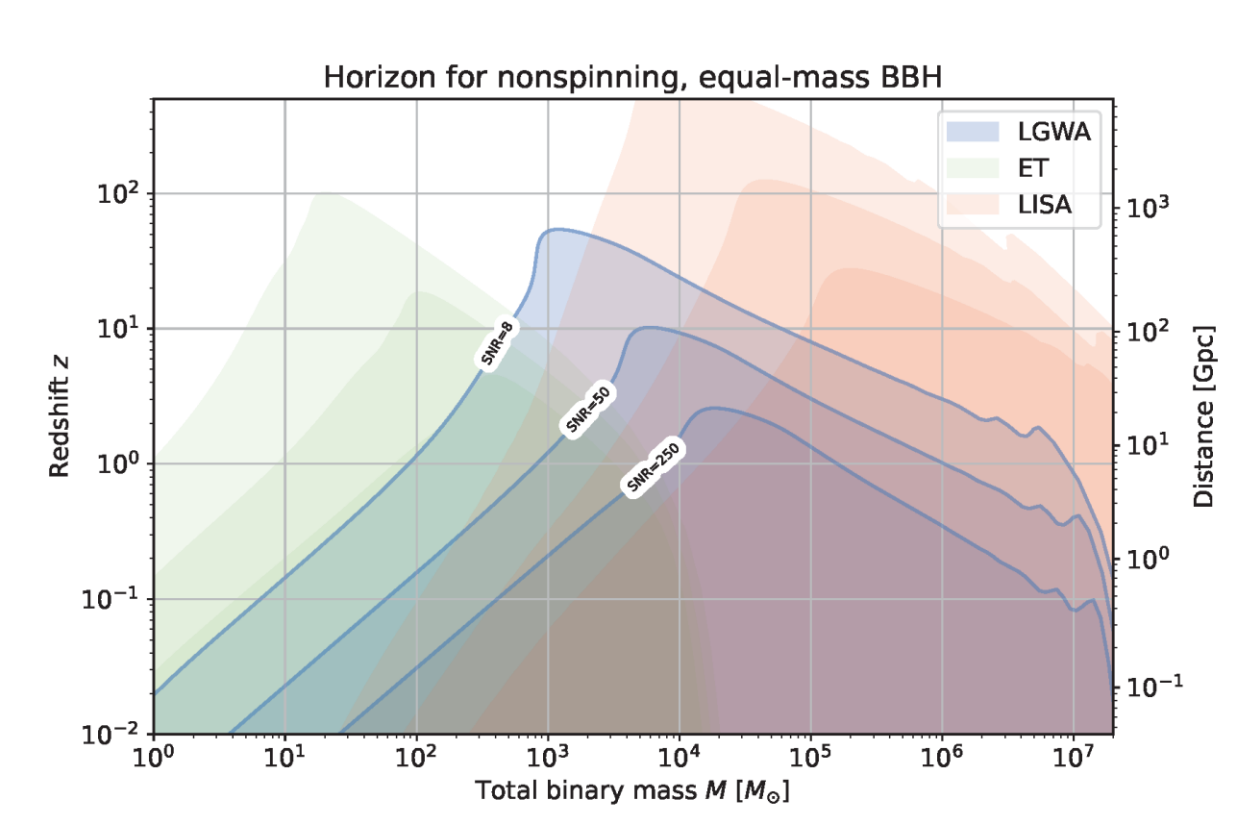
Lunar science
- Seismic sources
- Lunar internal structure
- Moon's formation history
- Geologic processes

Gravitational-wave science
- Astrophysical explosions and matter effects on waveforms
- Populations and formation channels of GW sources
- GW cosmology
- Fundamental physics with GWs

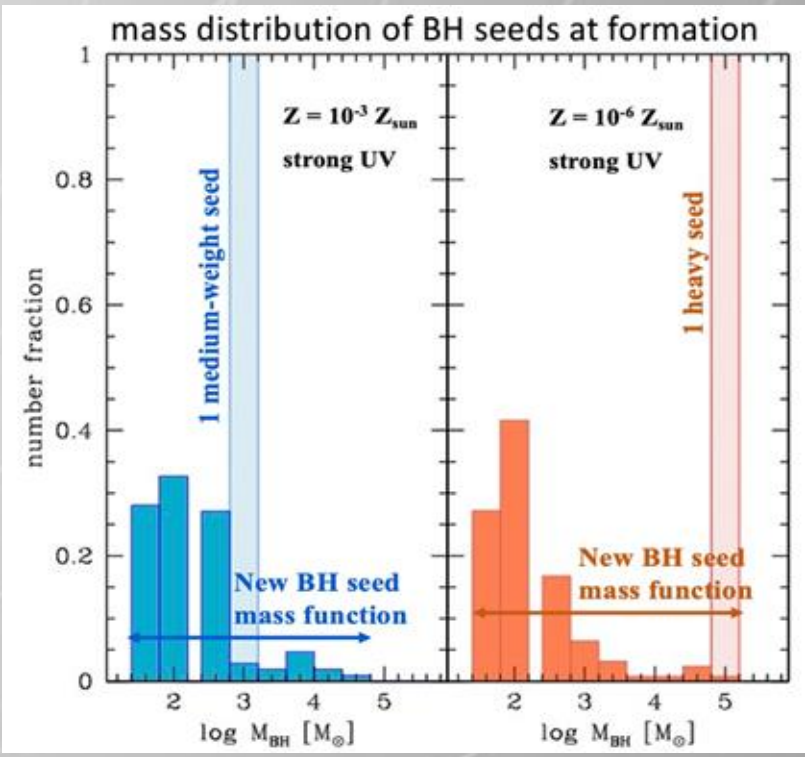
Multi-messenger observations
- Compact binaries with white dwarfs and neutron stars
- Supernovae
- Tidal Disruption Events
- Intermediate and Massive Black Hole Binaries
- Extreme/Intermediate Mass-ratio Inspirals

Detection Horizon

Detections of binary black holes out to high redshift



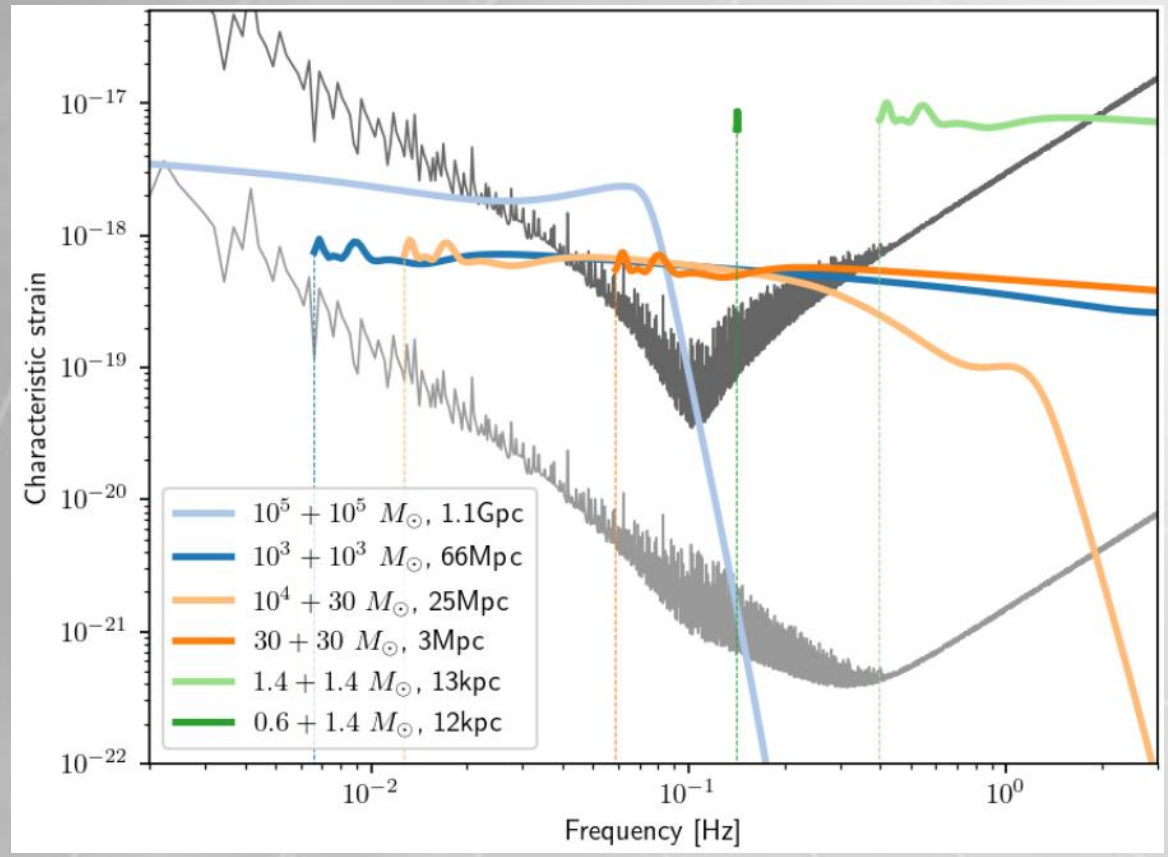
Study of the early population of seed black holes of today's supermassive BHs.

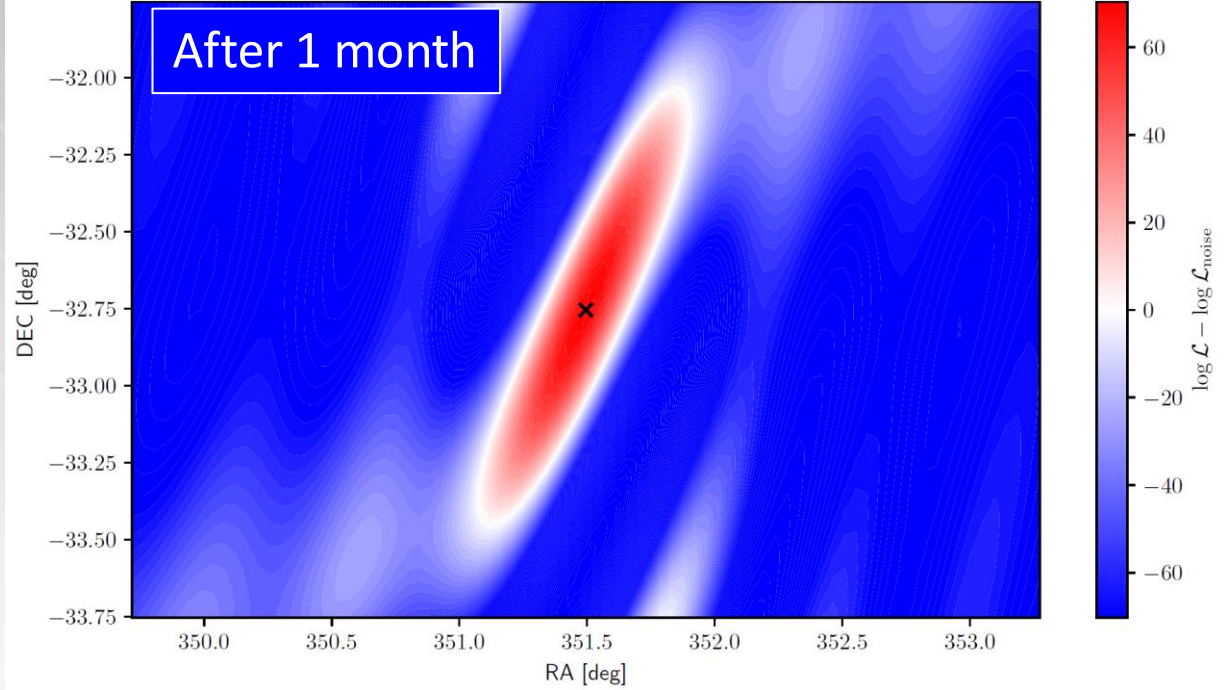


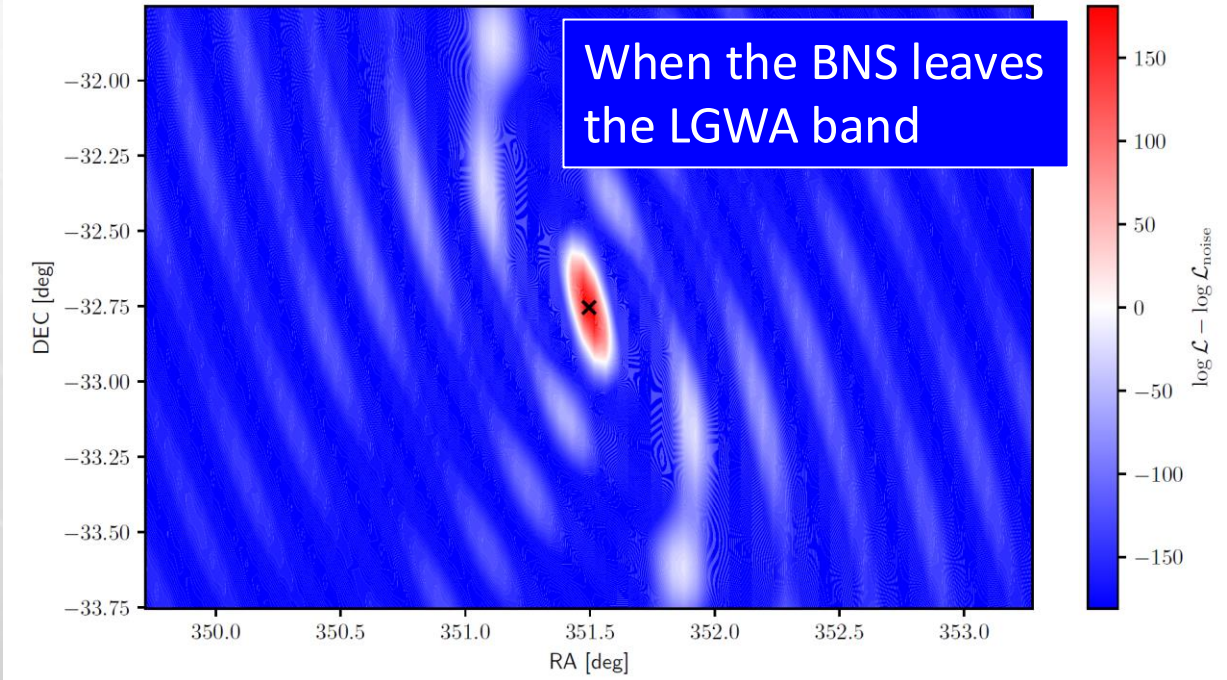
R Schneider et al

Sky Localization

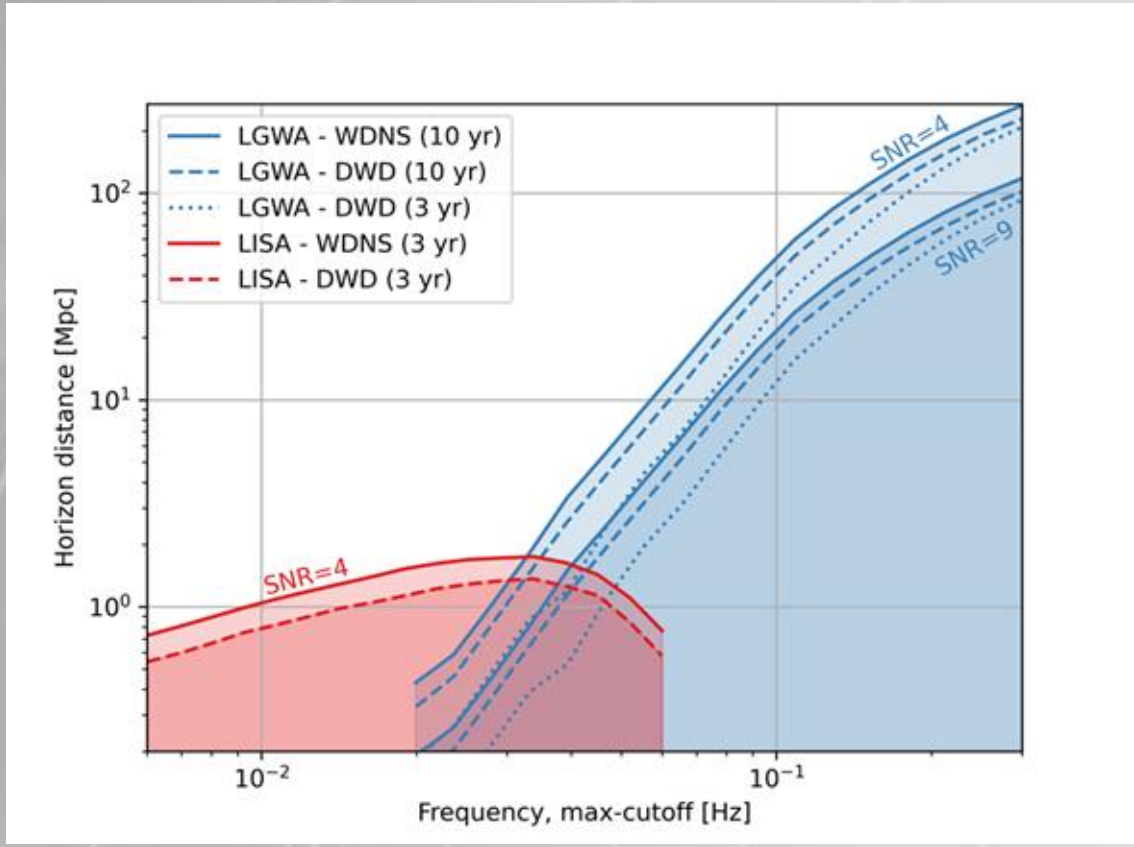
Sub deg^2 sky-localization of binary neutron stars for merger early warning





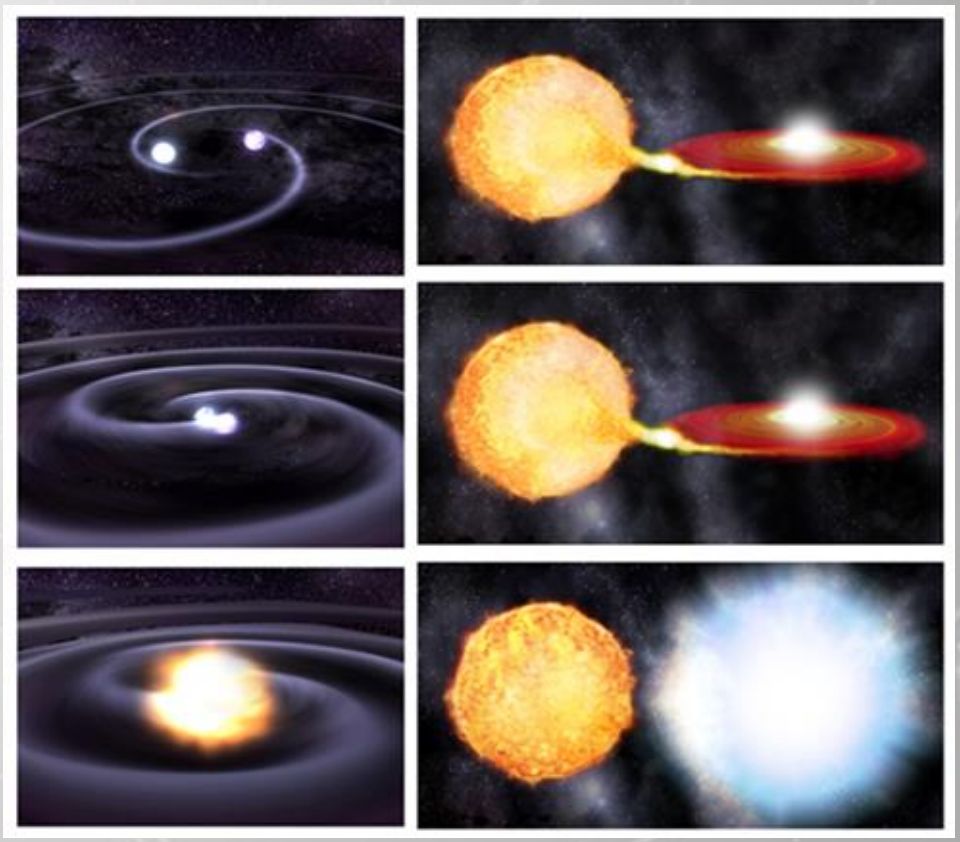


White-dwarf Mergers & SN Type Ia



What are the progenitors of Supernovae Type Ia?

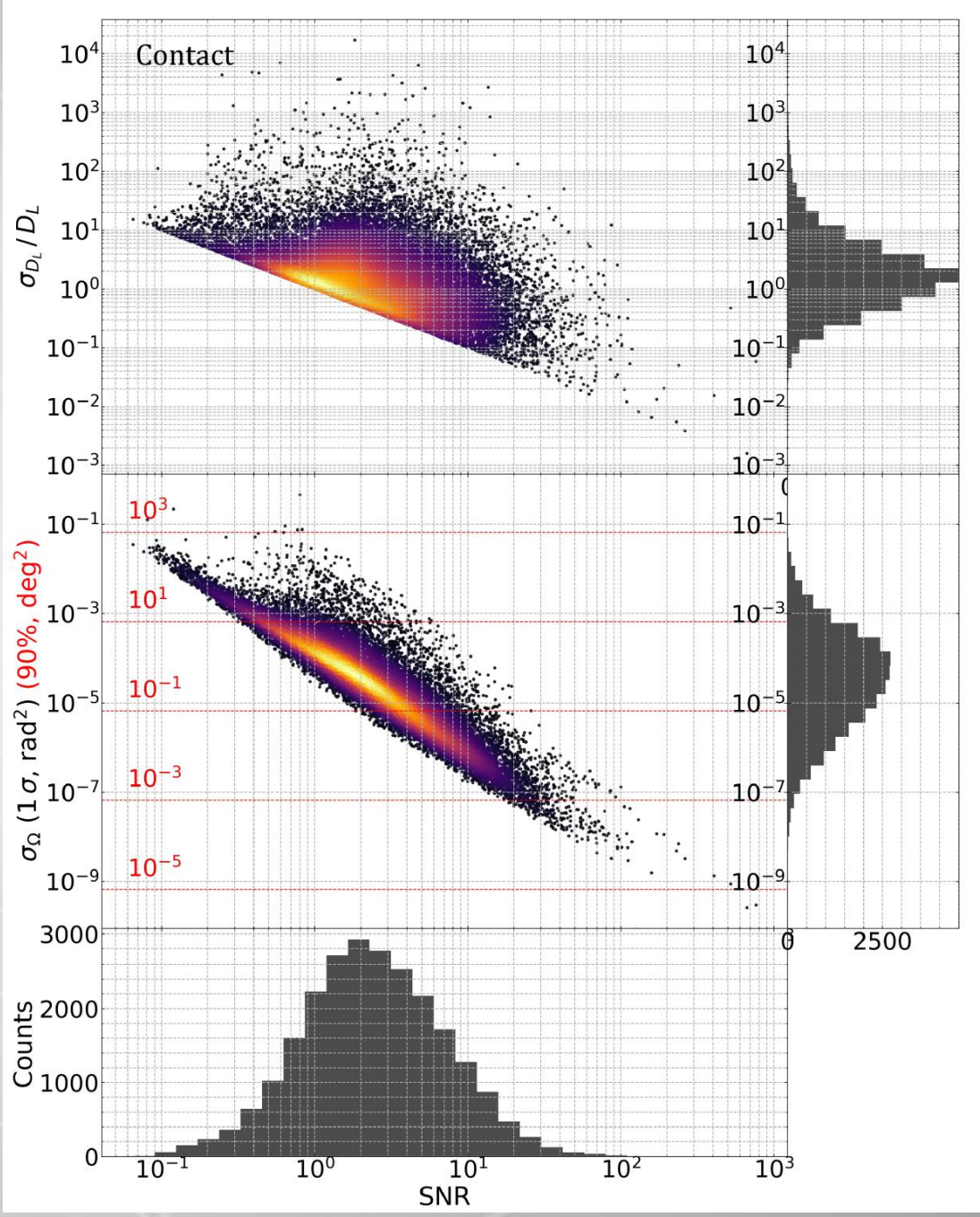
Double degenerate Single degenerate



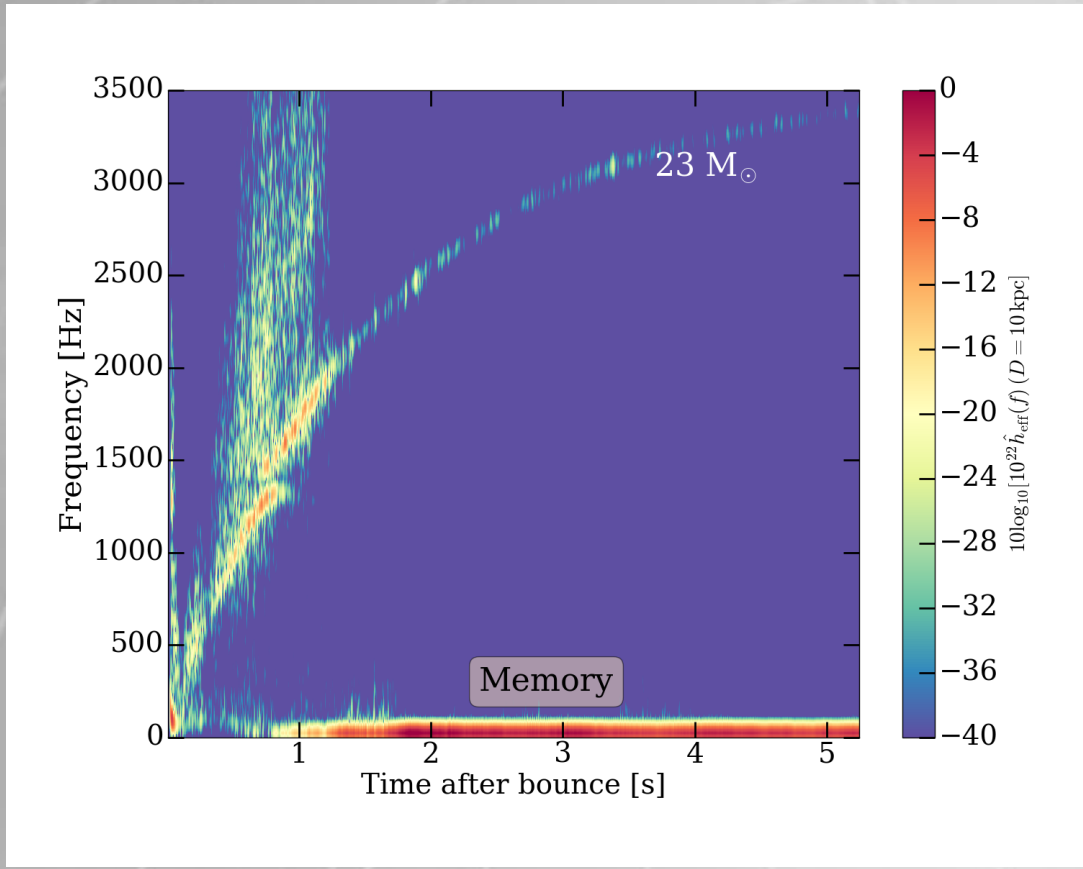
Recent Studies on DWDs

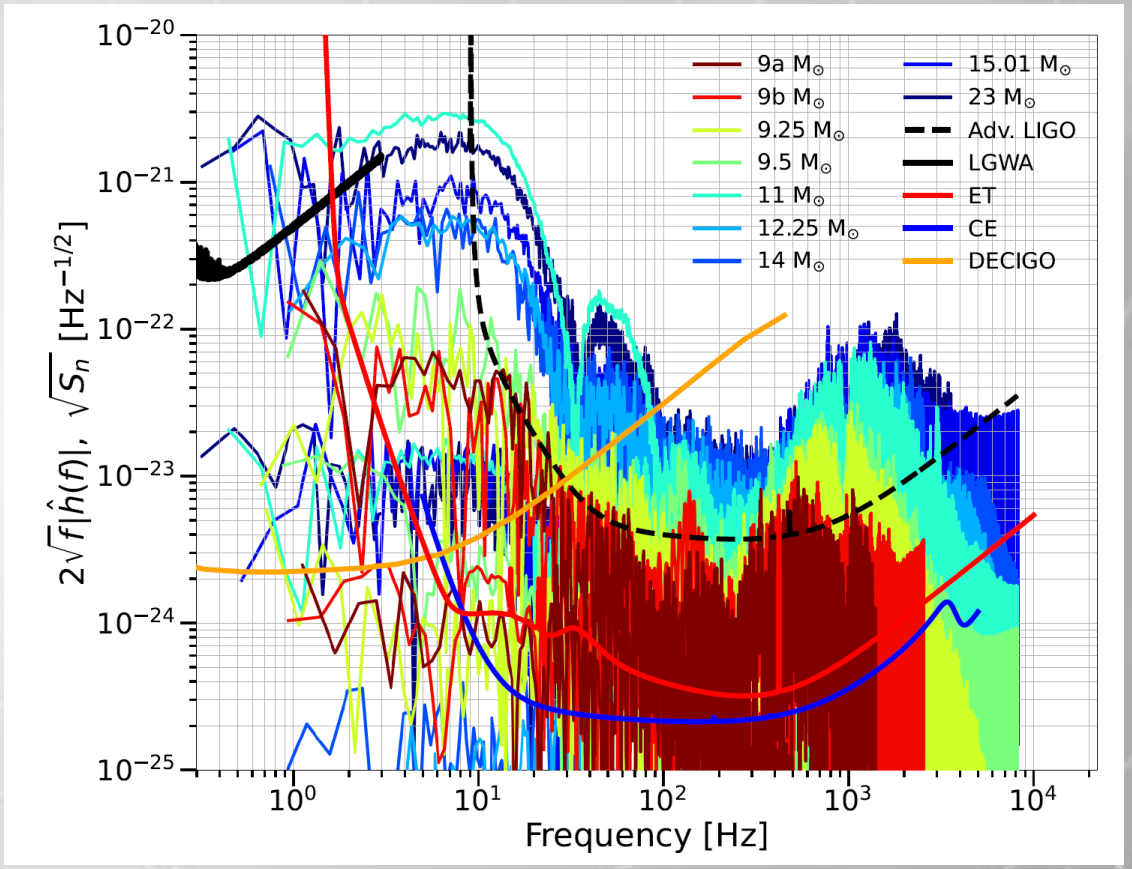
Benetti et al (2025):
Localization of a substantial fraction of DWDs in their host galaxy might be possible with LGWA with LGWA (depending on what exactly happens in the final phase before the merger).

Conclusion:
Decihertz GW detectors will provide a precise counterpart to SN1a-based Hubble-constant measurements.



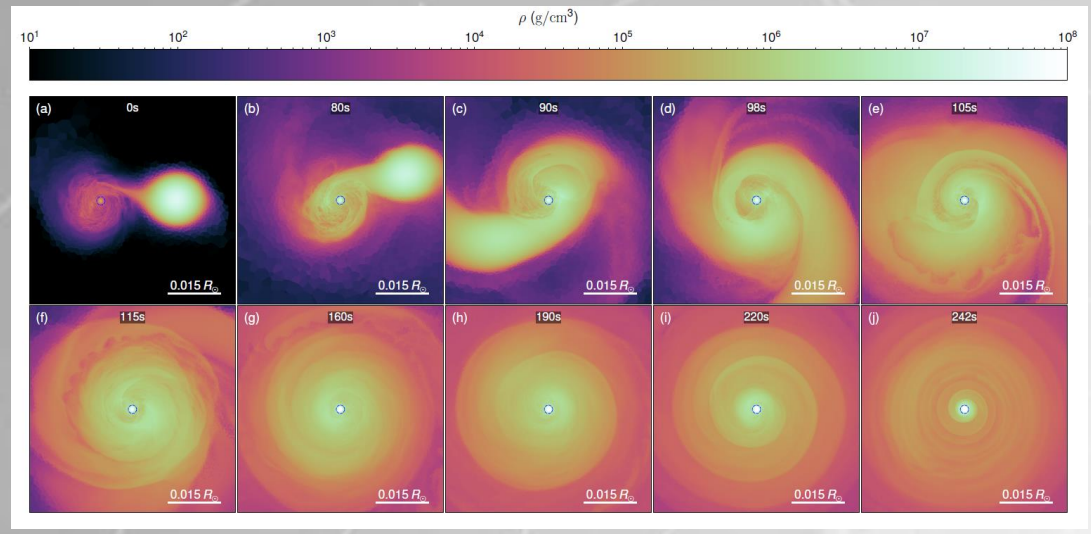
Core-collapse Sne and Memory Effects

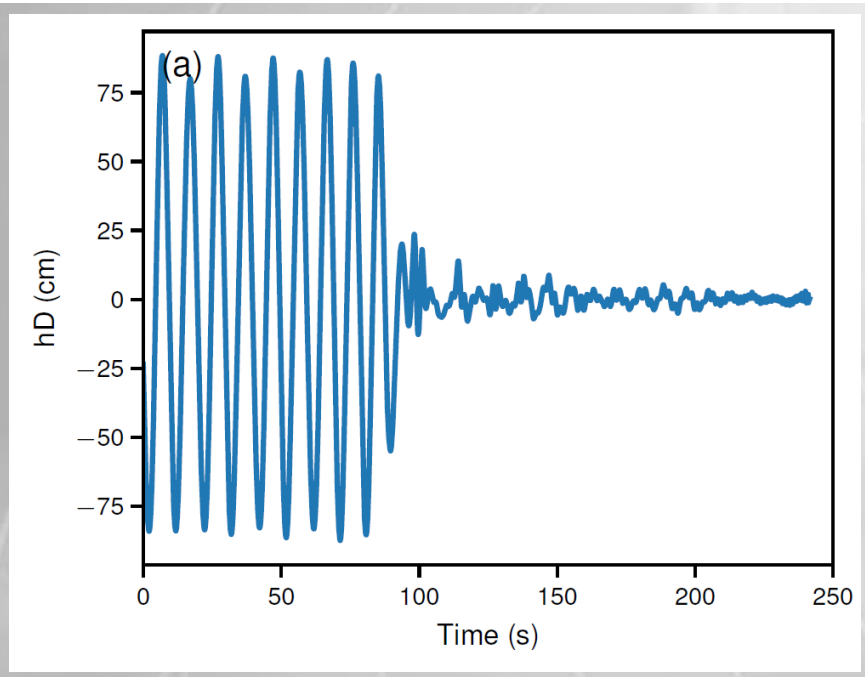


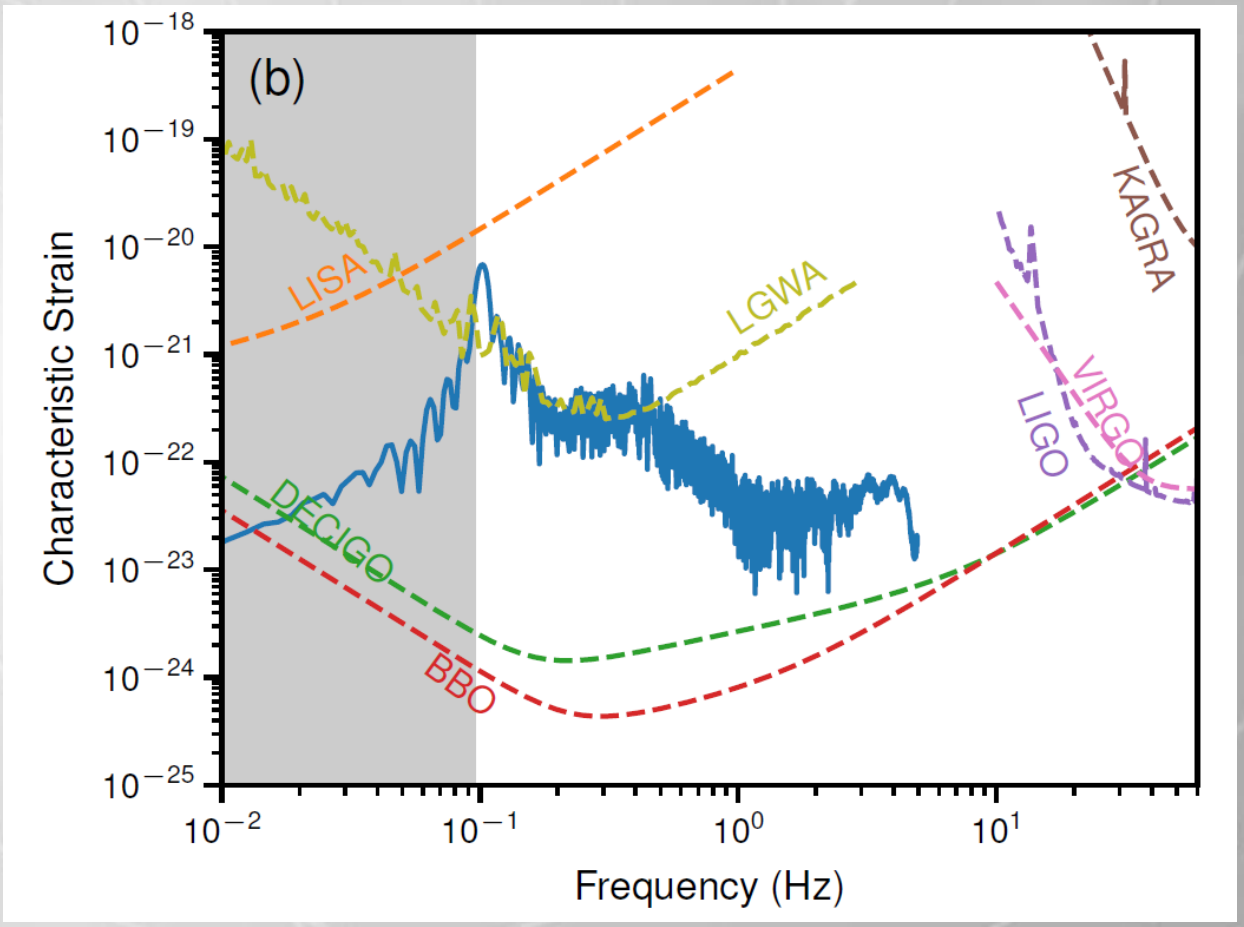


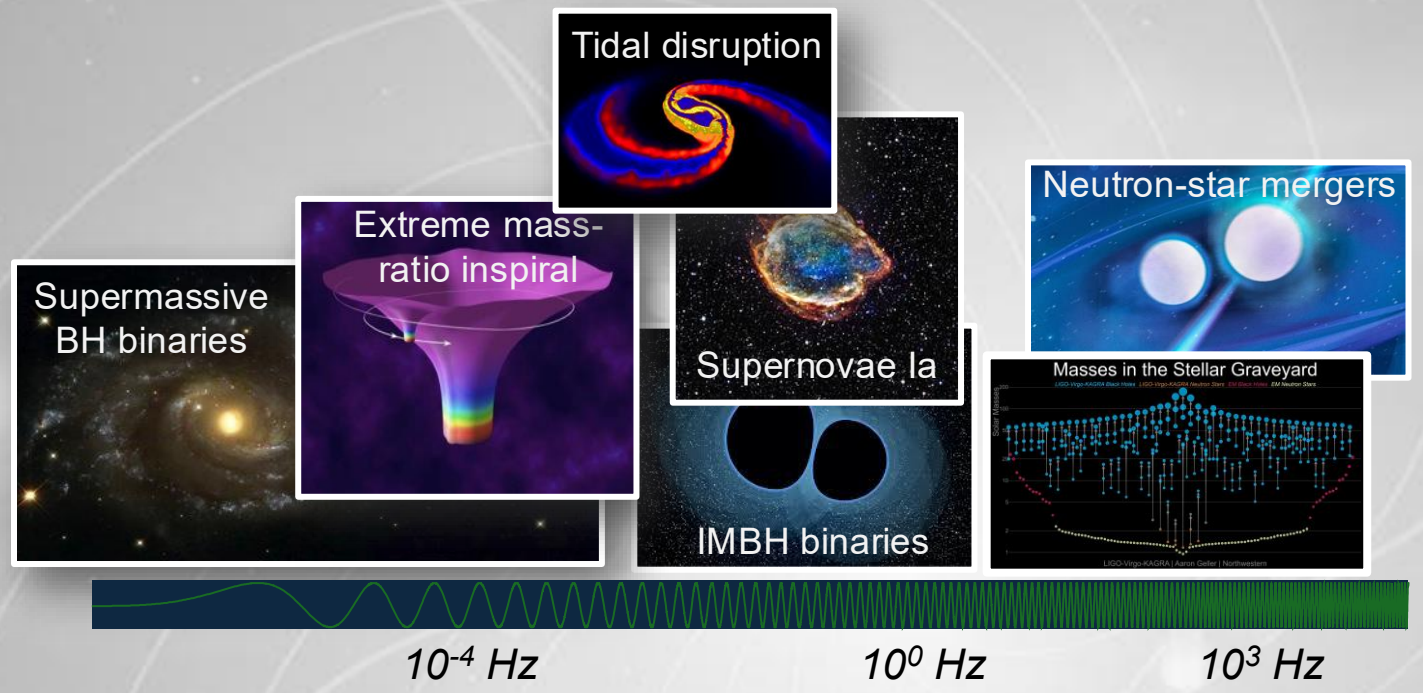
CCSN contain a low-frequency signal caused by the memory effect.

Tidal Disruptions, Example: WD- NS









Once the 3G terrestrial detectors are on their way, dHz GW detectors are the next big challenge in our field