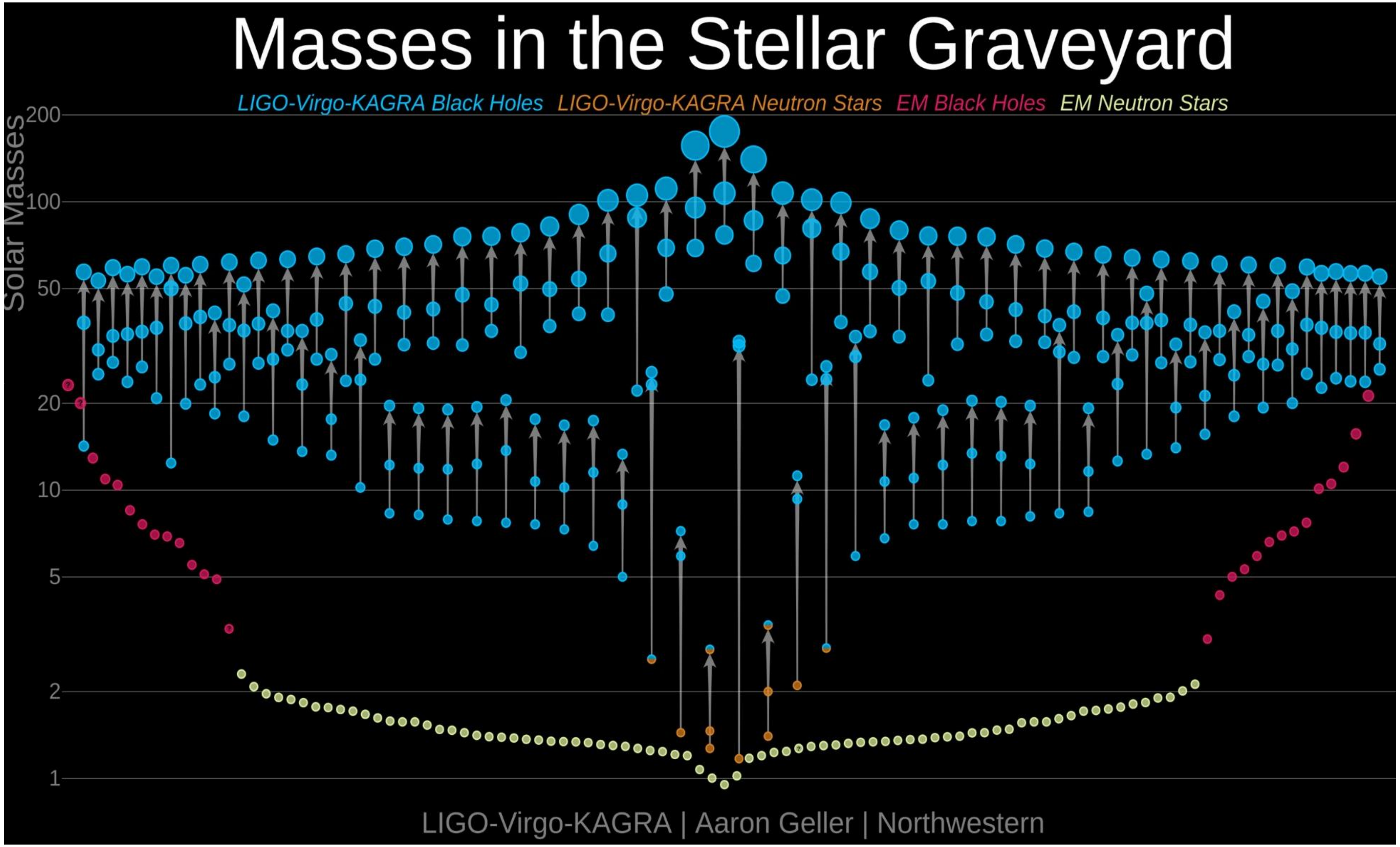
kHz Gravitational Wave Detectors

Haixing Miao

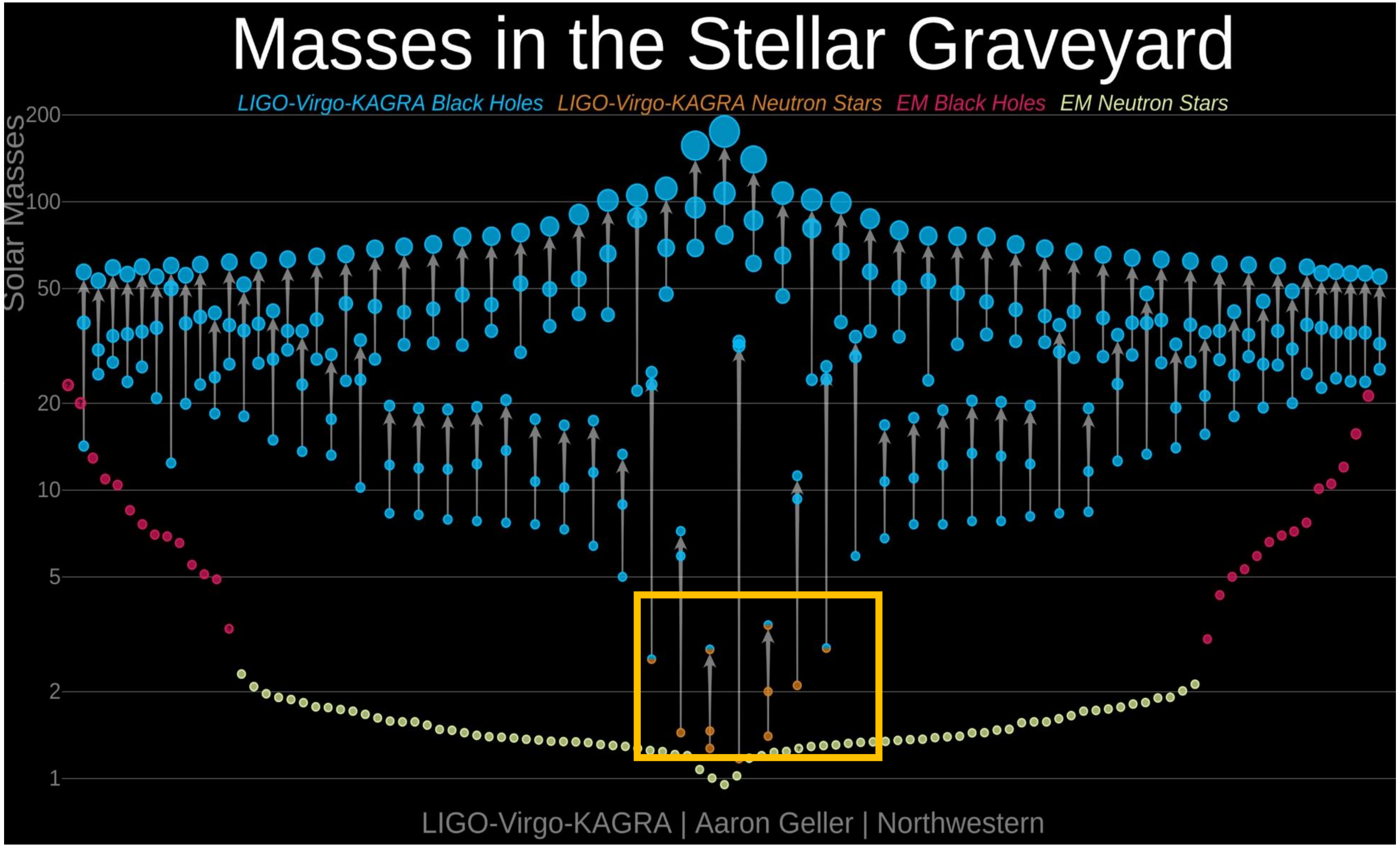
(缪海兴)

Detections @ O3



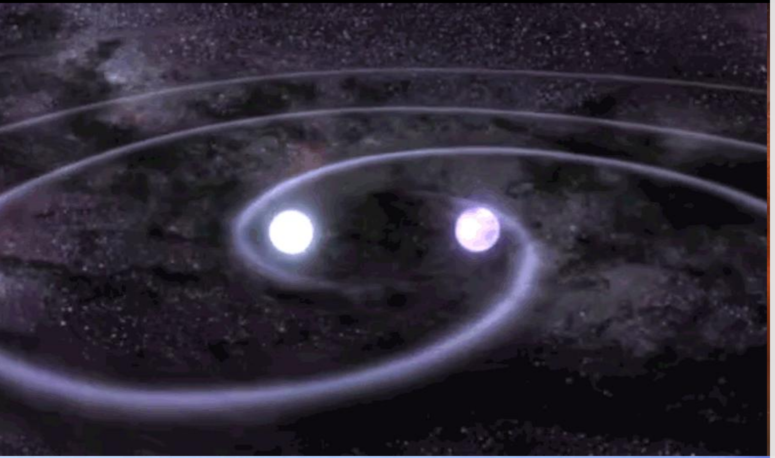
LIGO-Virgo-KAGRA collaboration, *GWTC-3: Compact Binary Coalescences Observed by LIGO and Virgo During the Second Part of the Third Observing Run*, arXiv: 2111.03606 (2021).

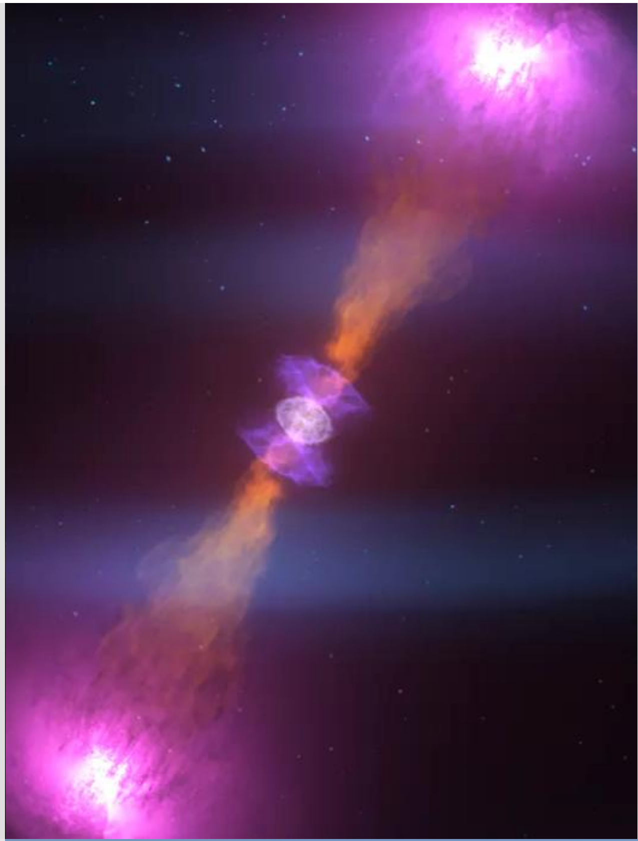
Detections @ O3



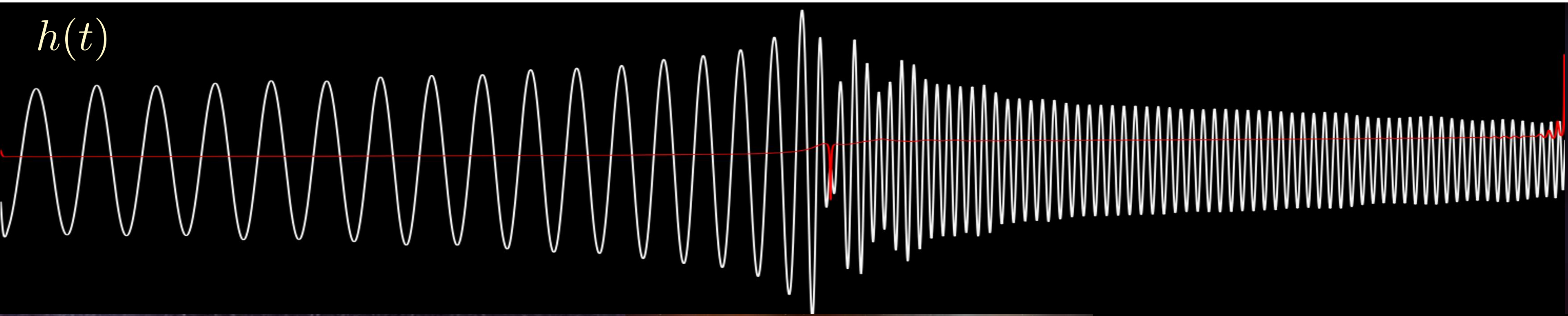
LIGO-Virgo-KAGRA collaboration, *GWTC-3: Compact Binary Coalescences Observed by LIGO and Virgo During the Second Part of the Third Observing Run*, arXiv: 2111.03606 (2021).

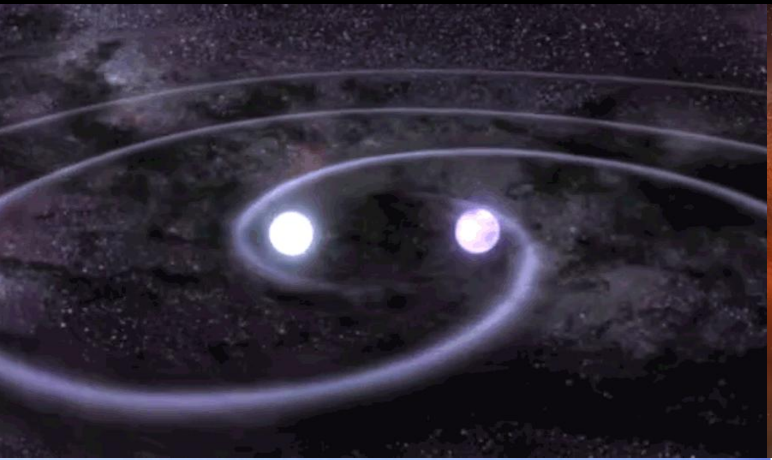
GW170817

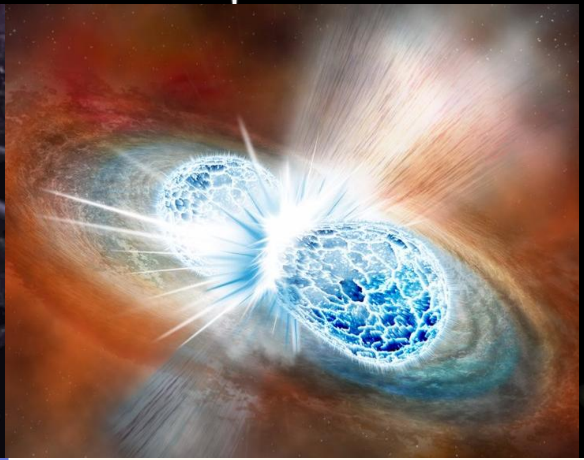


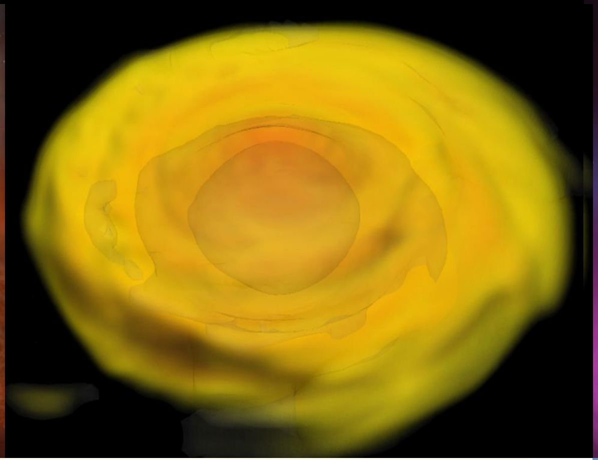


GW170817









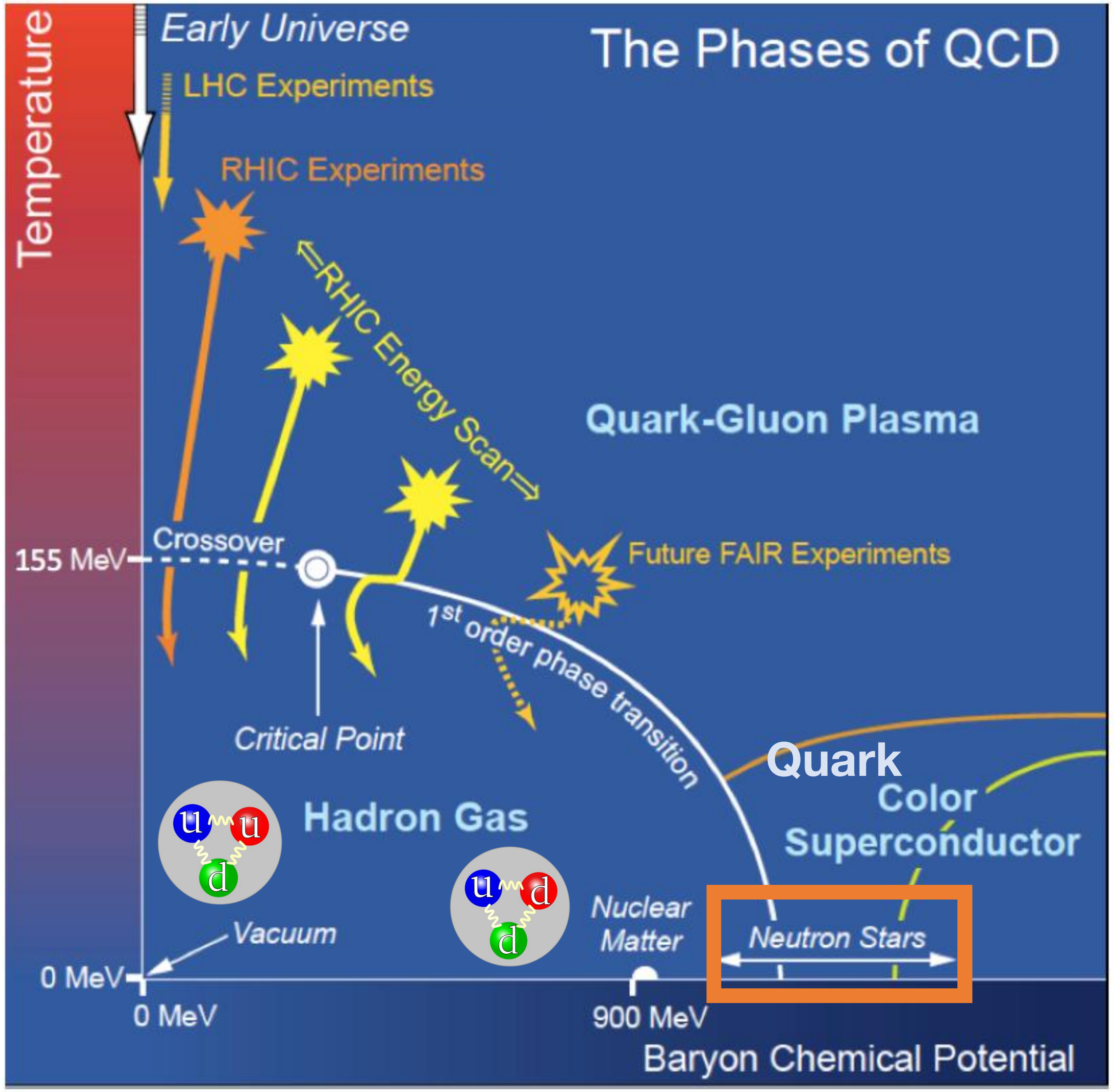
kHz GW detectors

Science cases of post-merger kHz GWs

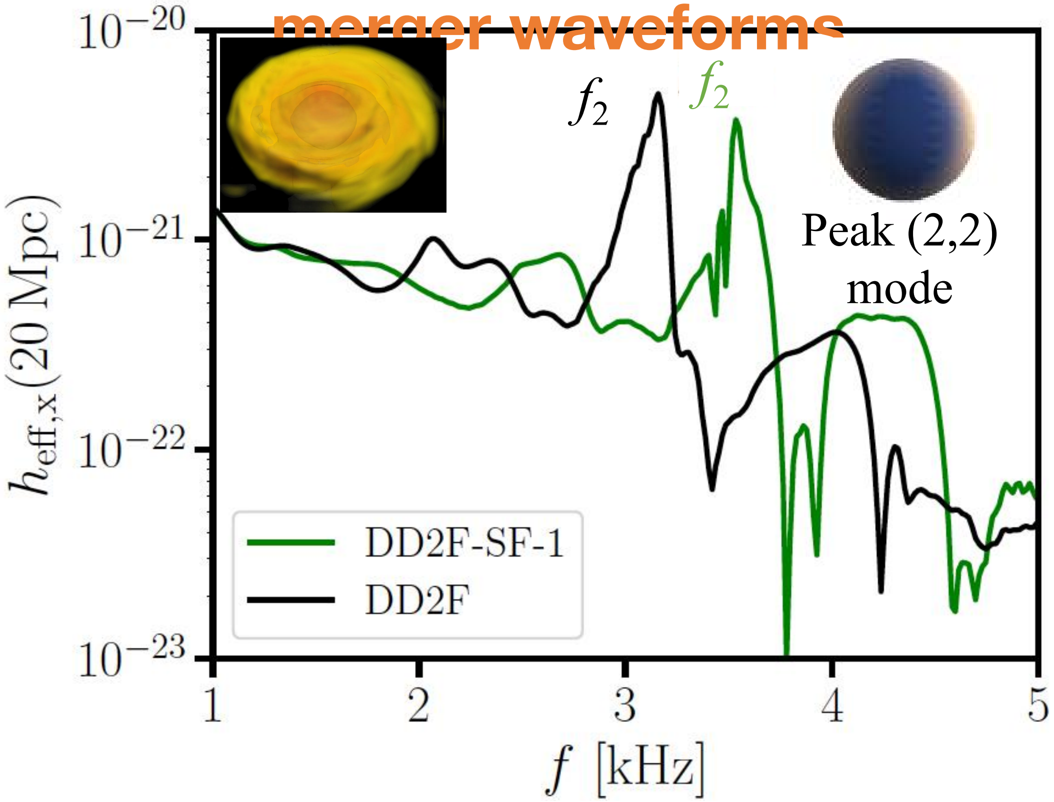
N. Andersson *et al*., *Gravitational waves from neutron stars: promises and challenges*, Gen. Relativ. Gravit. **43**, 409 (2011).
L. Baiotti, and L. Rezzolla, *Binary neutron star mergers: a review of Einstein's richest laboratory*, Rep. Prog. Phys. **80**, 096901 (2017).

Also Elias Most's talk on Tuesday

Studying QCD Matter



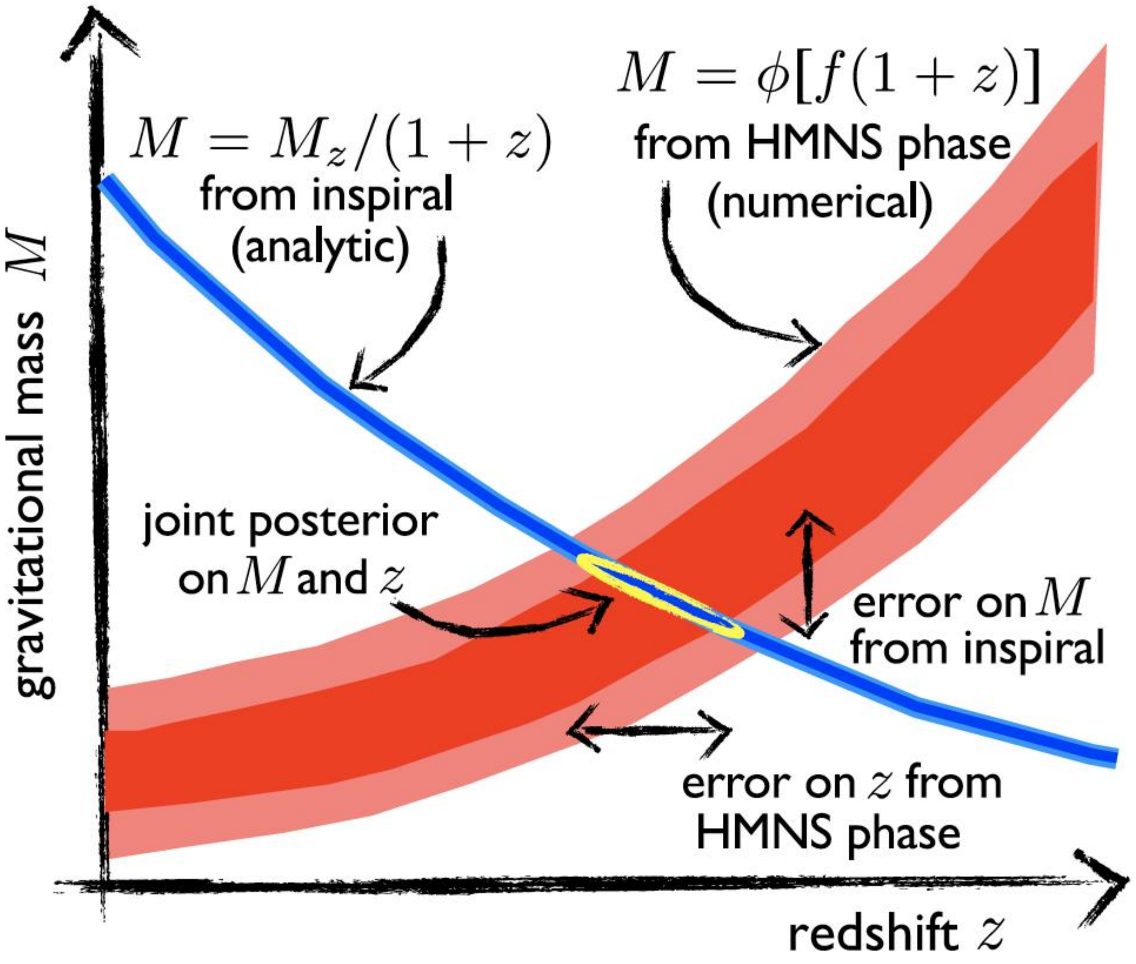
Transition from hadrons to deconfined quarks affects post-merger waveforms

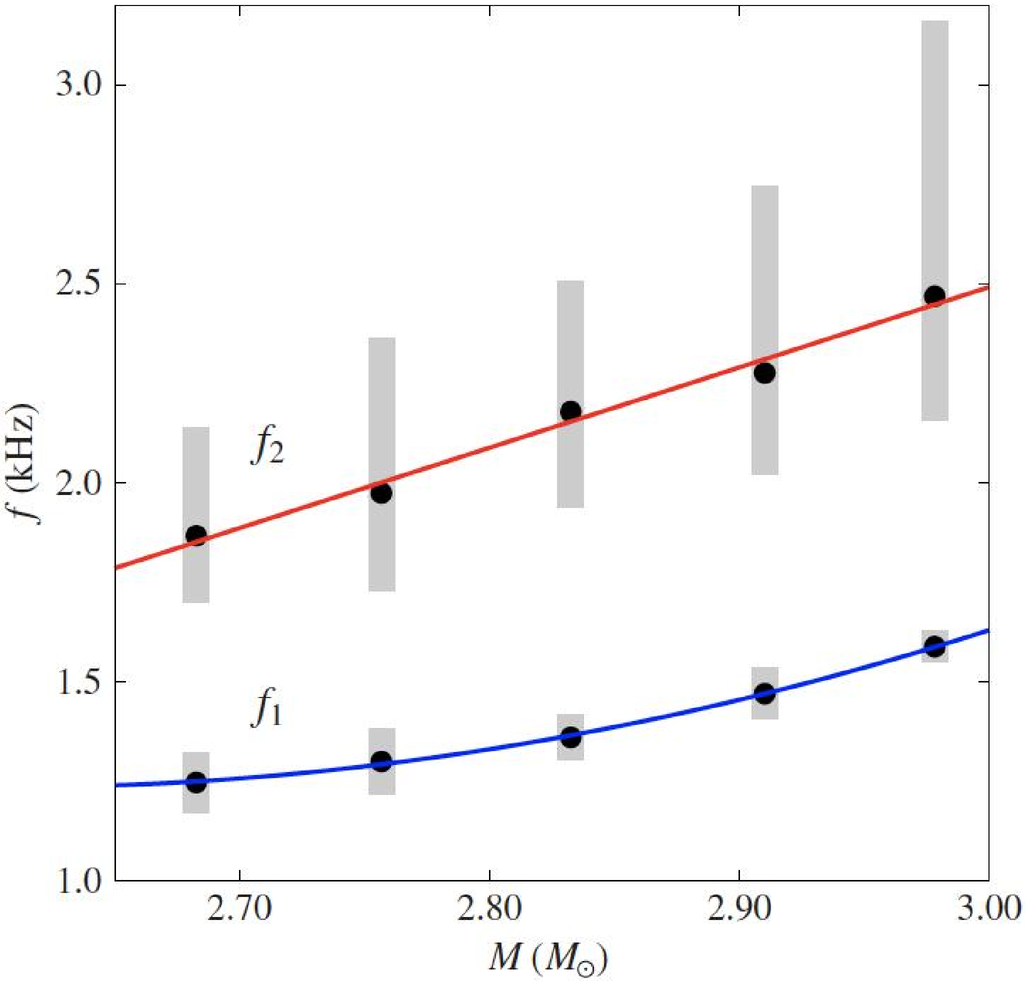


[1] A. Bauswein *et al.*, *Identifying a First-Order Phase Transition in Neutron-Star Mergers through GWs*, PRL 2019.

[2] E. Most *et al.*, *Signatures of Quark-Hadron Phase Transitions in General-Relativistic Neutron-Star Mergers*, PRL 2019.

Measuring Hubble Constant

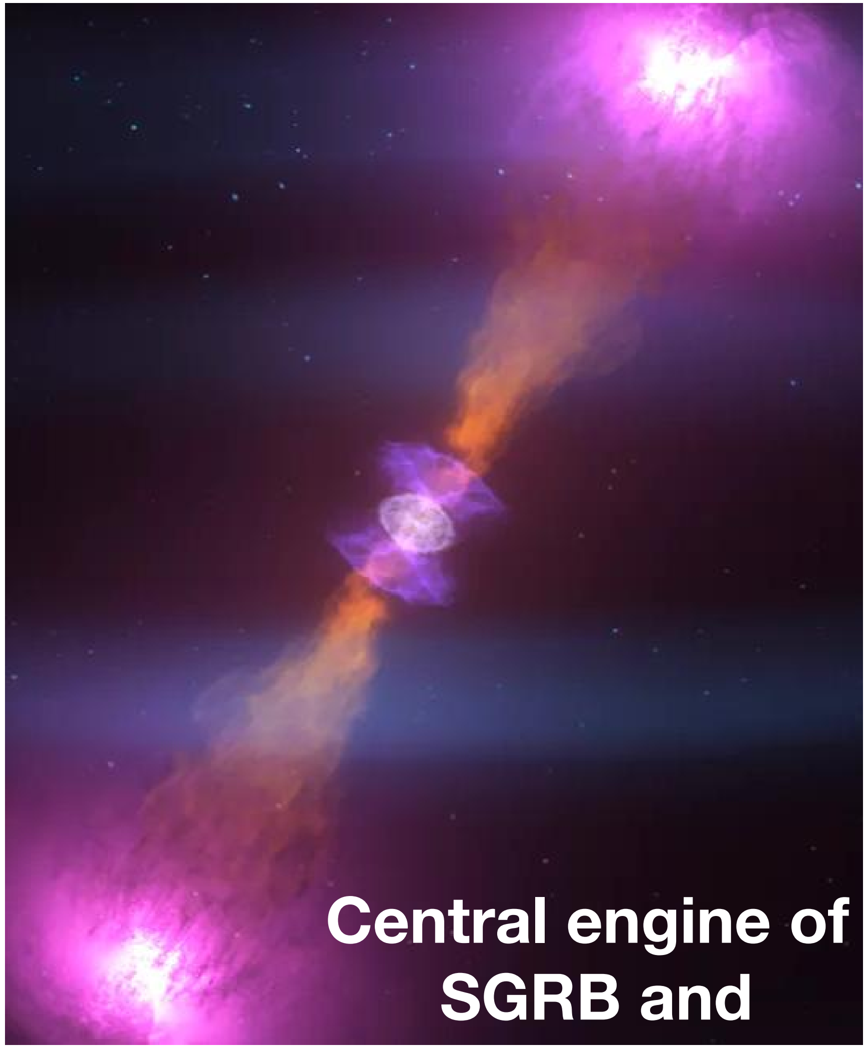


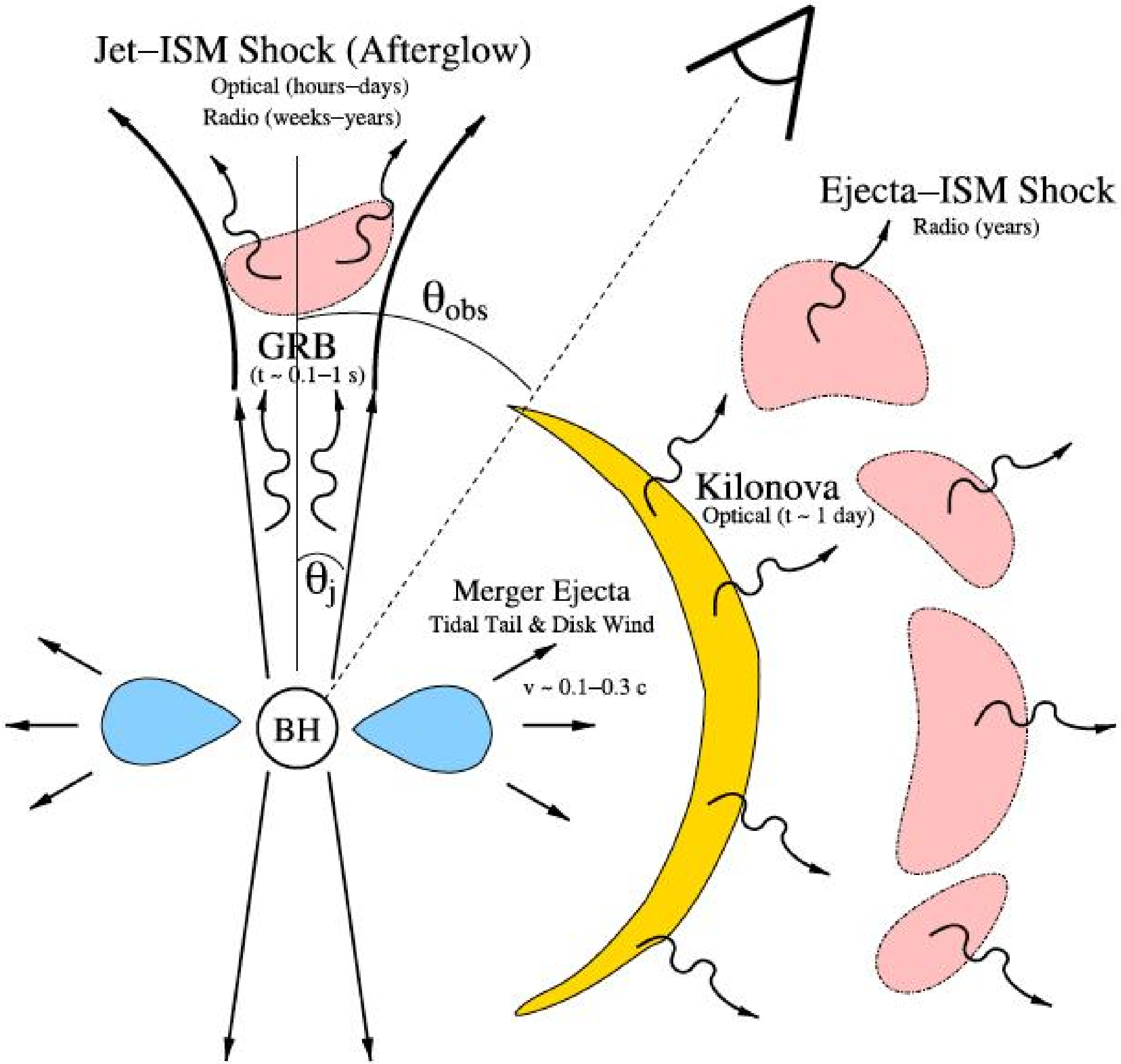


C. Messenger *et al.*, *Source Redshifts from GW Observations of BNS Mergers*, Phy. Rev. X **4**, 041004 (2014)

Using matter effect to break redshift-mass degeneracy.

Short Gamma-ray Burst and Kilonova

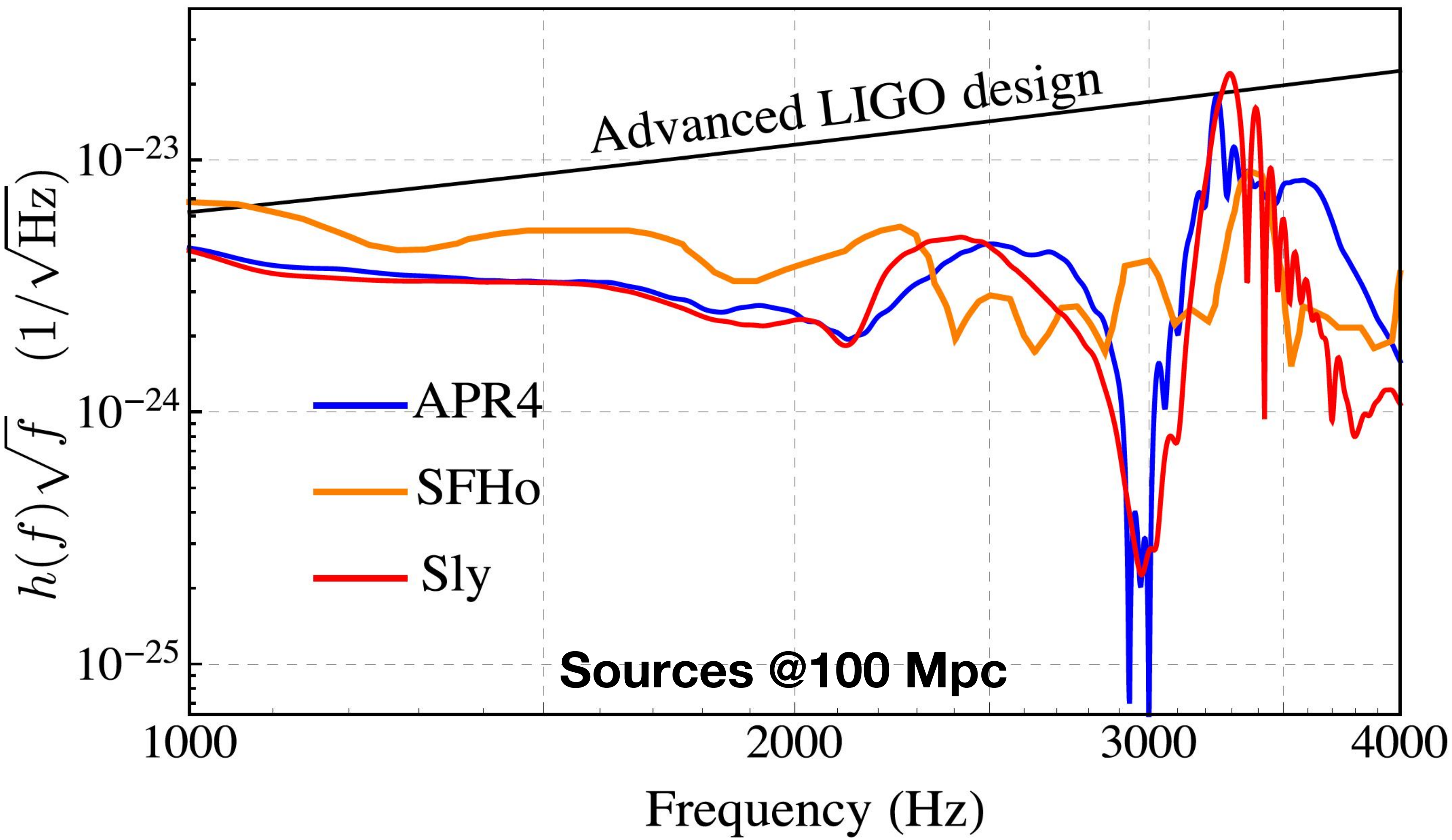




Metzger and Berger, *What is the most promising electromagnetic counterpart of a BNS merger*? ApJ **746**, 48 (2012)

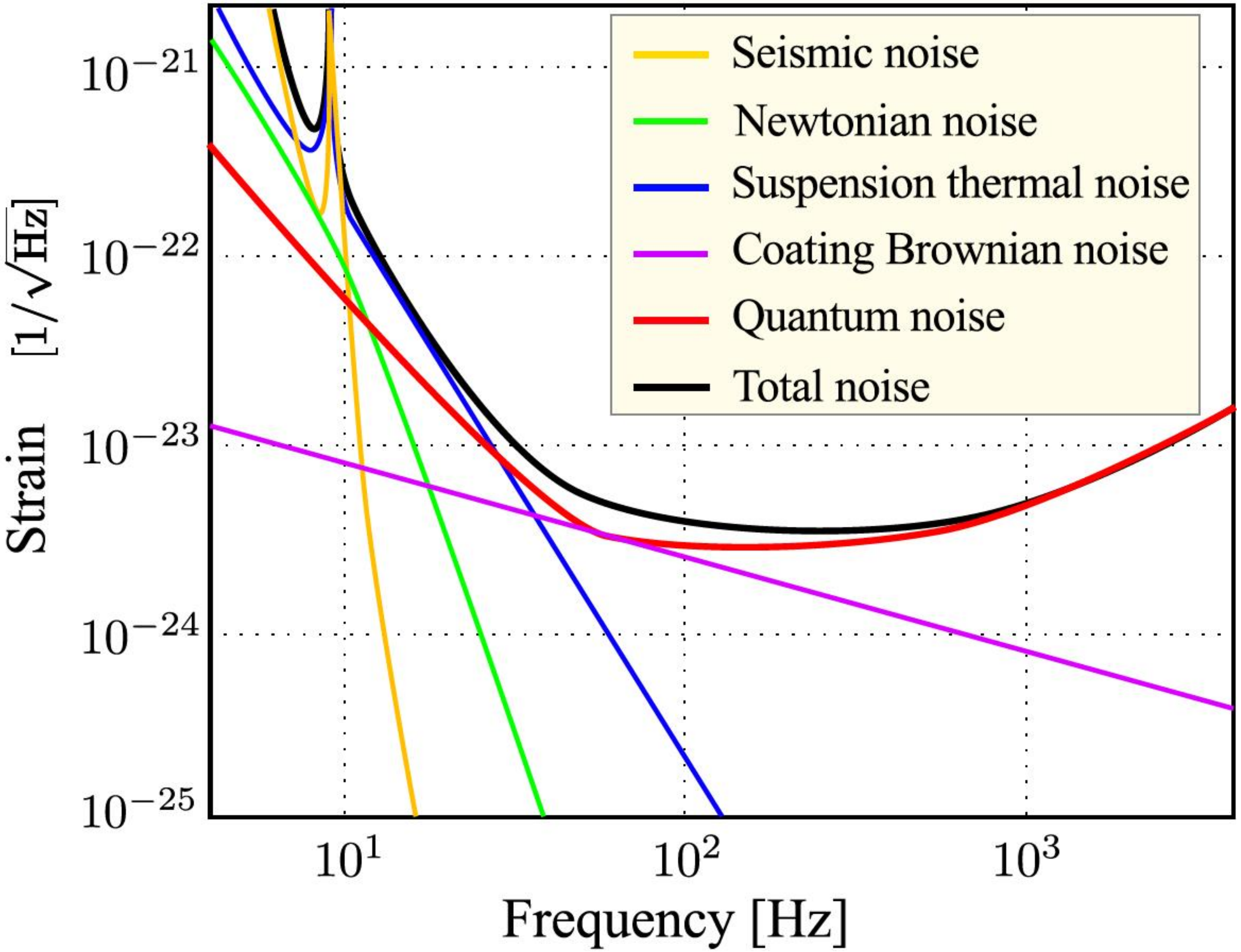
Why so difficult to detect them?

Detection Challenge

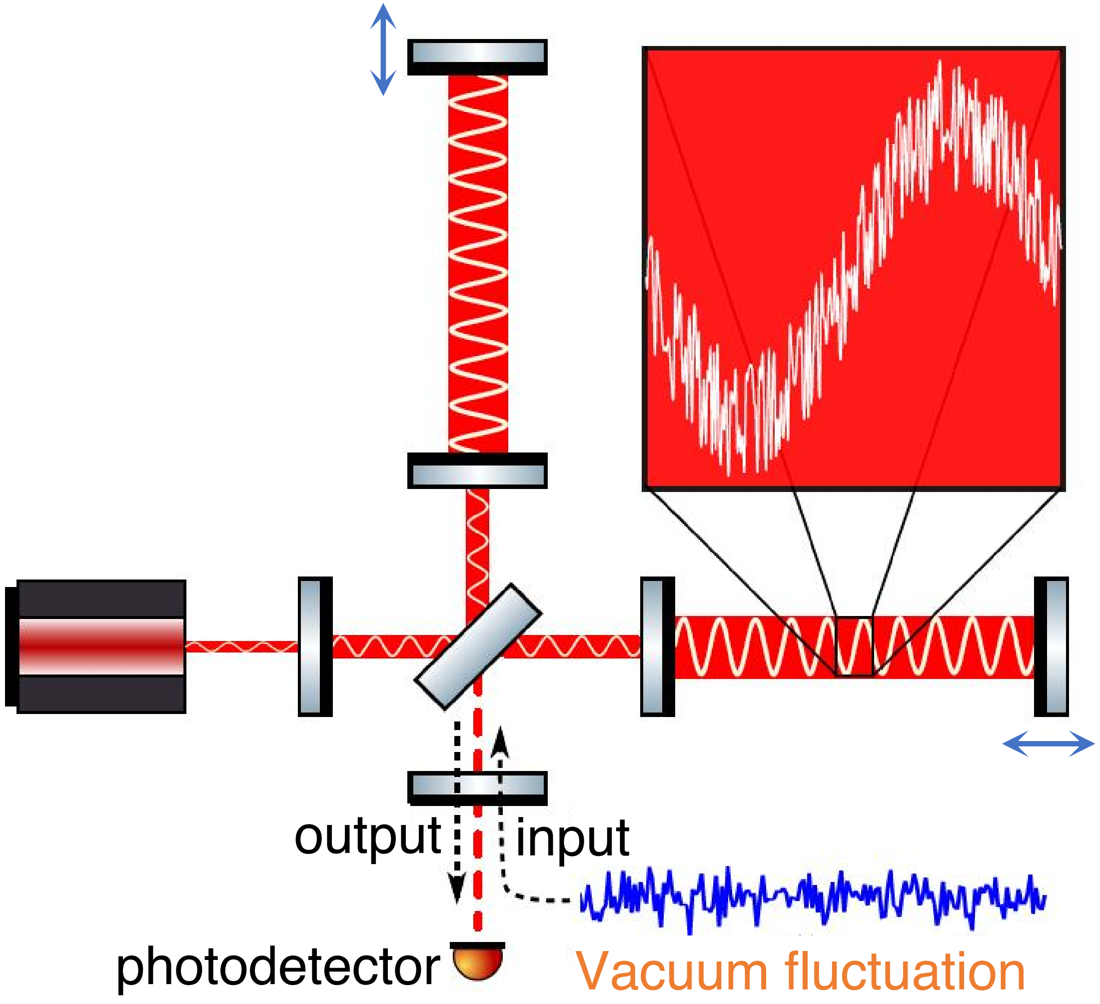


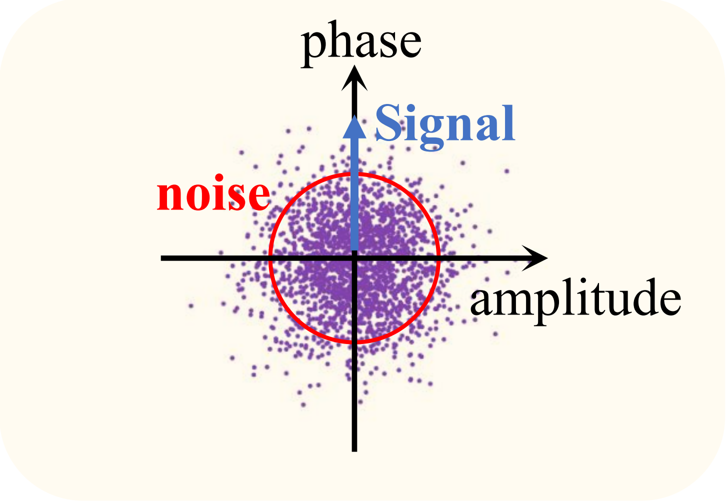
Making confident detections requires a sensitivity better than 10^{-24} @ kHz

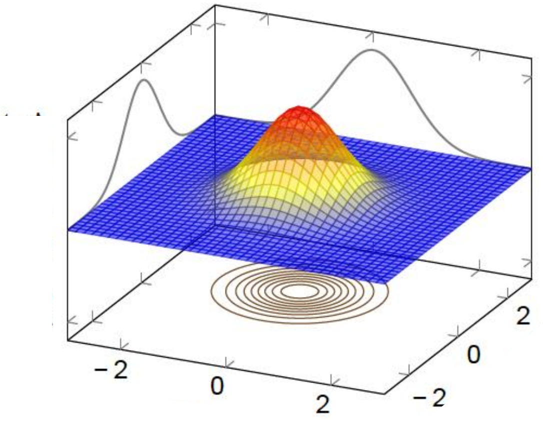
Limiting Noise Above 1kHz



What is Quantum Noise?

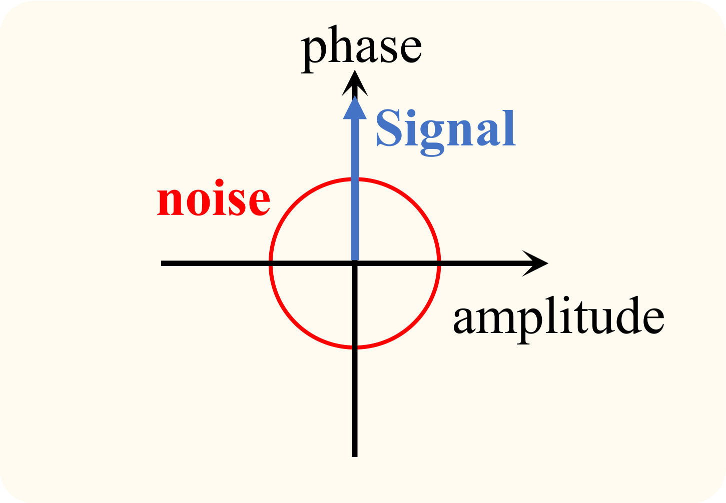






How to Reduce Quantum Noise?

Amplifying the Signal

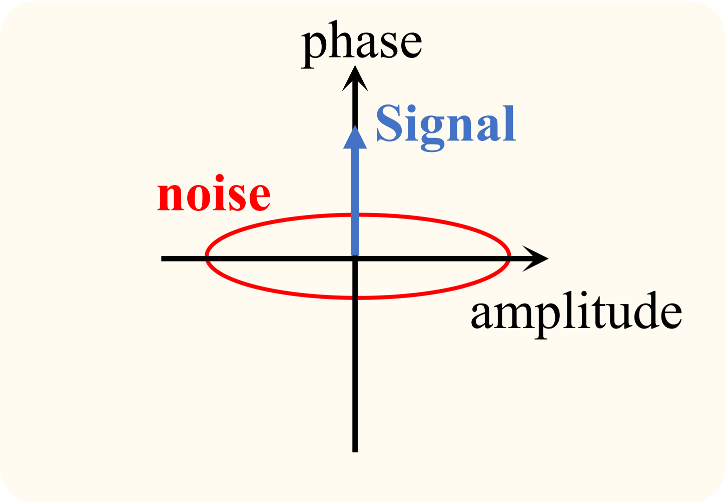


Higher power

Longer arm length

Coherent amplification

Reducing the Noise

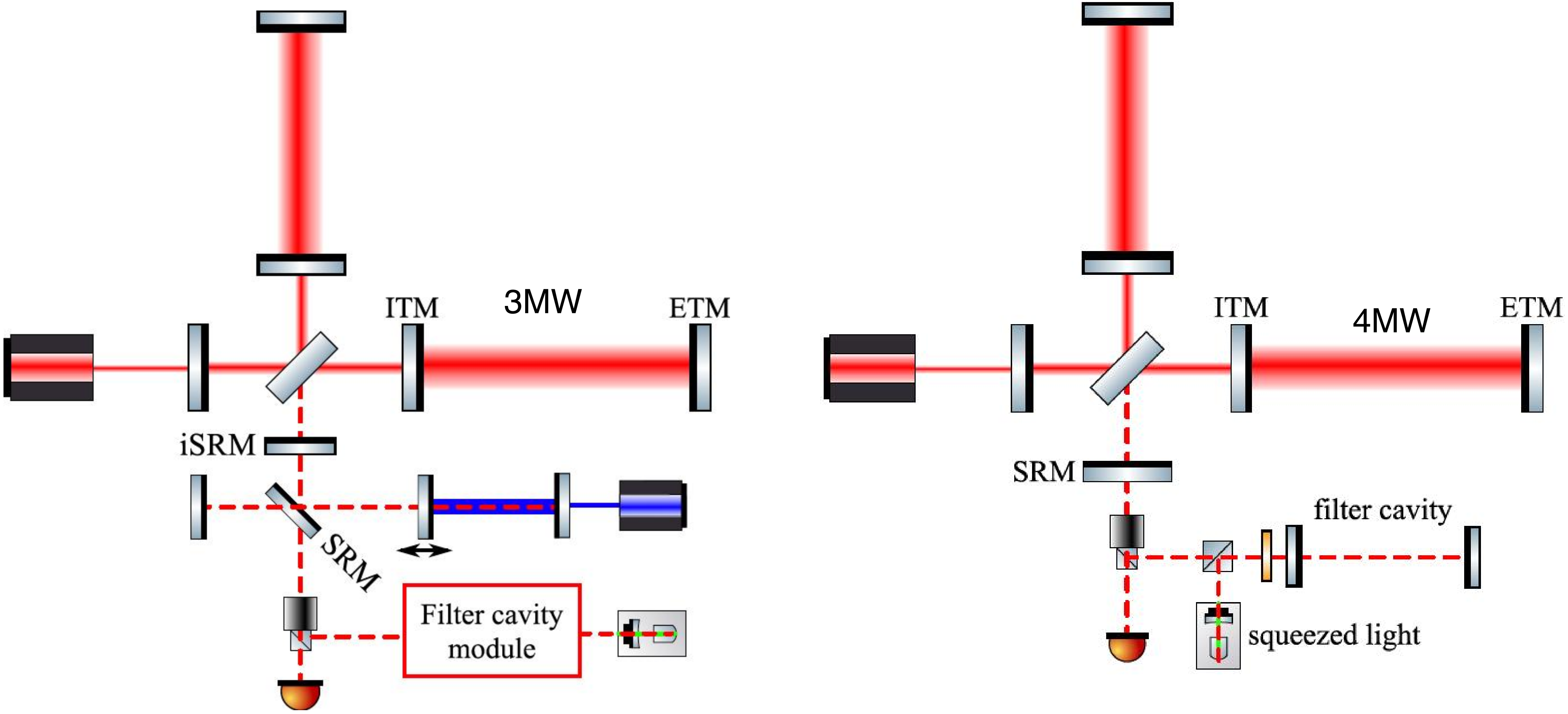


Quantum squeezed light

S. Danilishin, F. Khalili, and H. Miao, *Advanced quantum techniques for future GW detectors*, Living Reviews in Relativity **22**, 2 (2019); LIGO Scientific Collaboration, *Instrument Science White Paper* (2023).

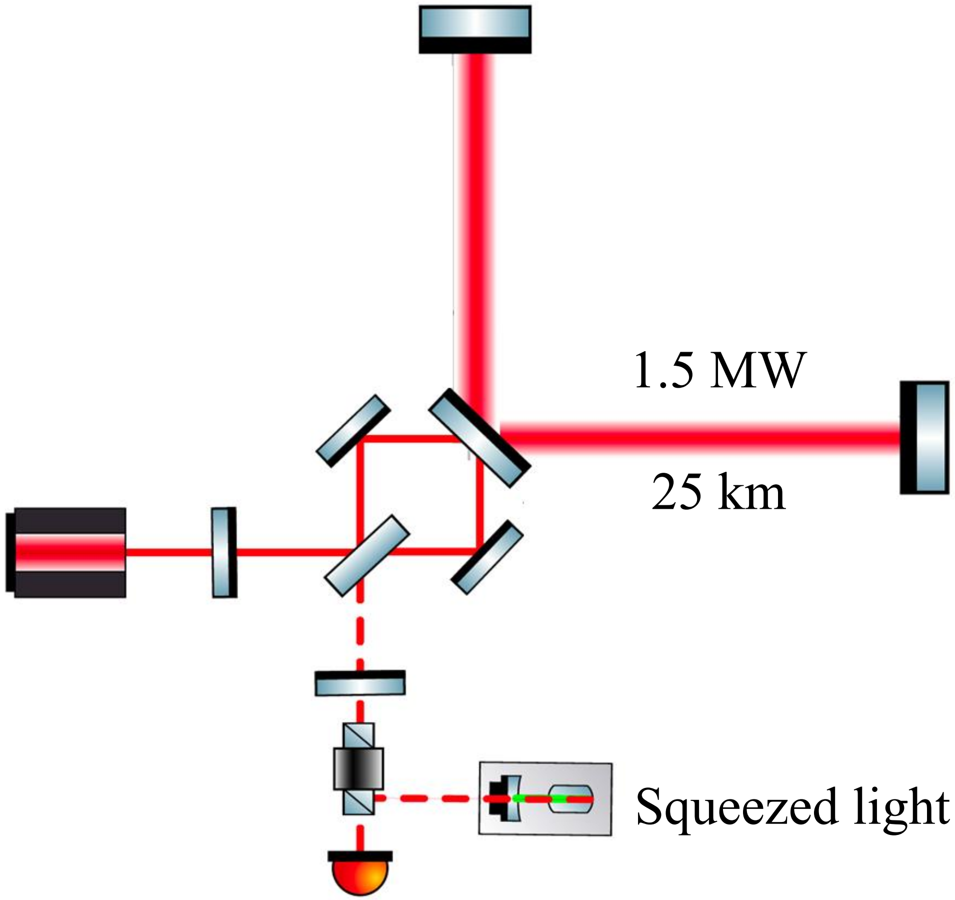
kHz GW detector designs

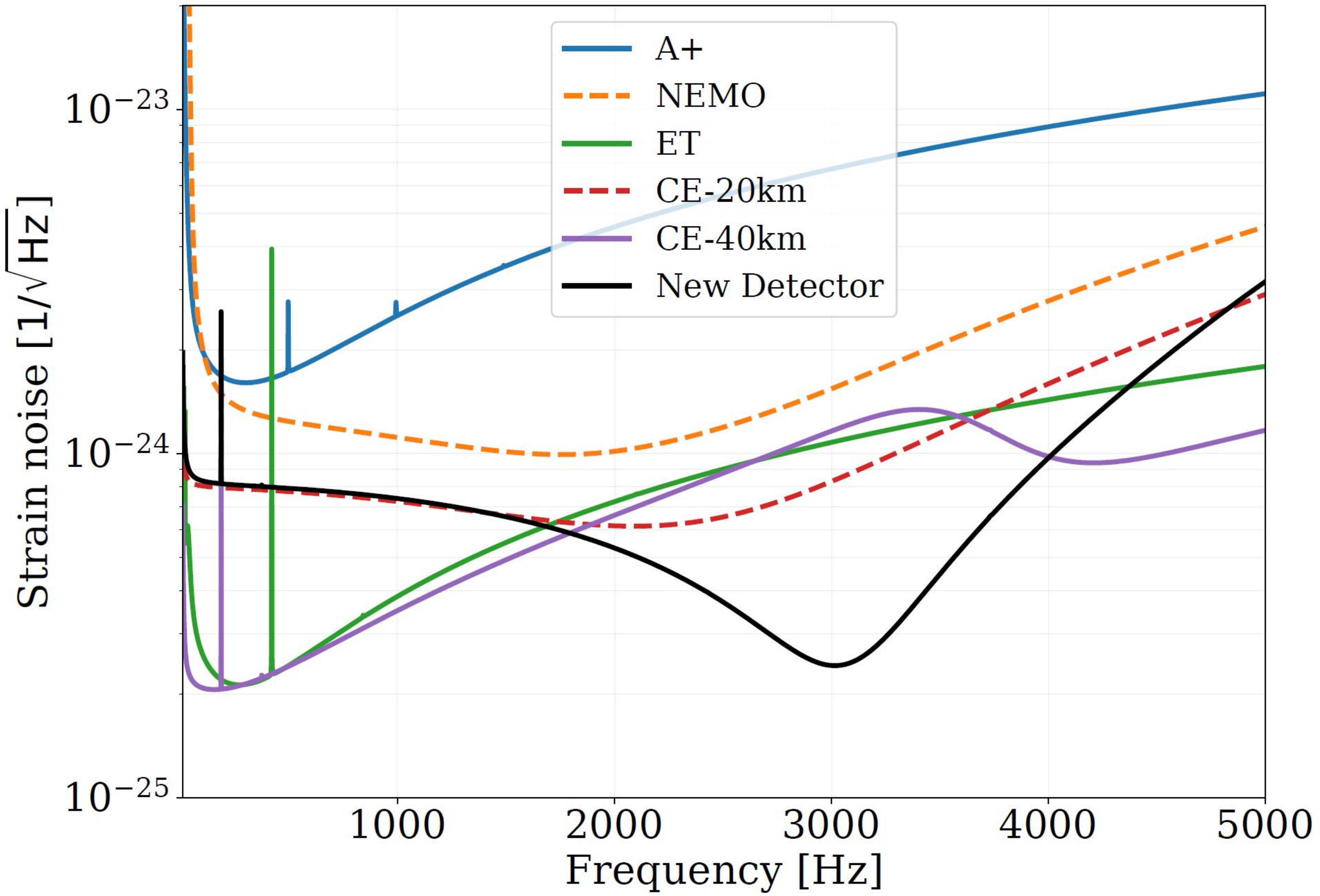
LIGO-HF Concept



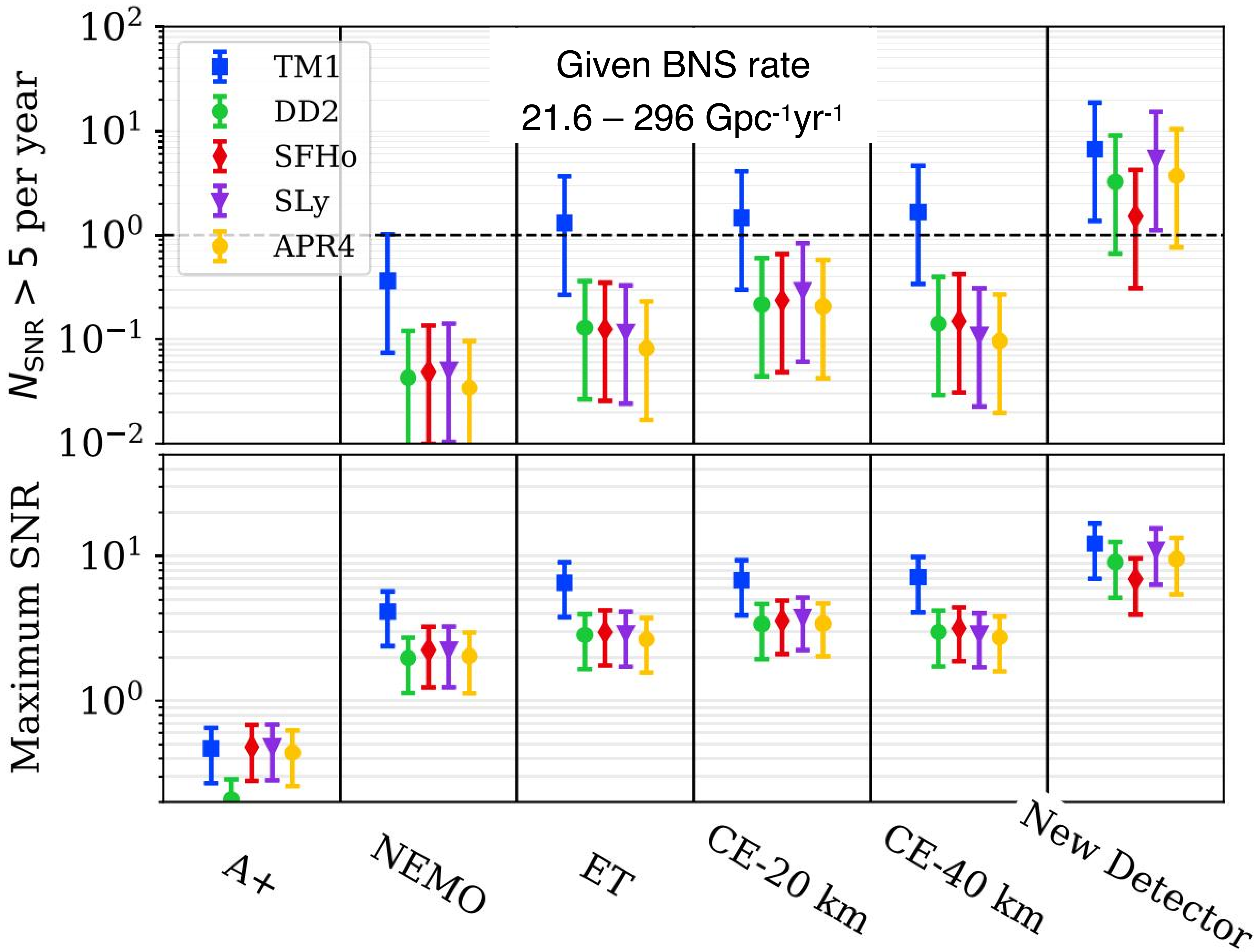
H. Miao, H. Yang* and D. Martynov, *Towards the design of GW detectors for probing neutron-star physics*, Phys. Rev. D **98**, 044044 (2018); D. Martynov, H. Miao and H. Yang *et al***.** Phys. Rev. D **99**, 102004 (2019).

New Detector Design: Beyond Michelson





T. Zhang , H. Yang , D. Martynov, P. Schmidt, and H. Miao, *Gravitational-Wave Detector for Postmerger Neutron Stars*
Phys. Rev. X **13**, 021019 (2023)



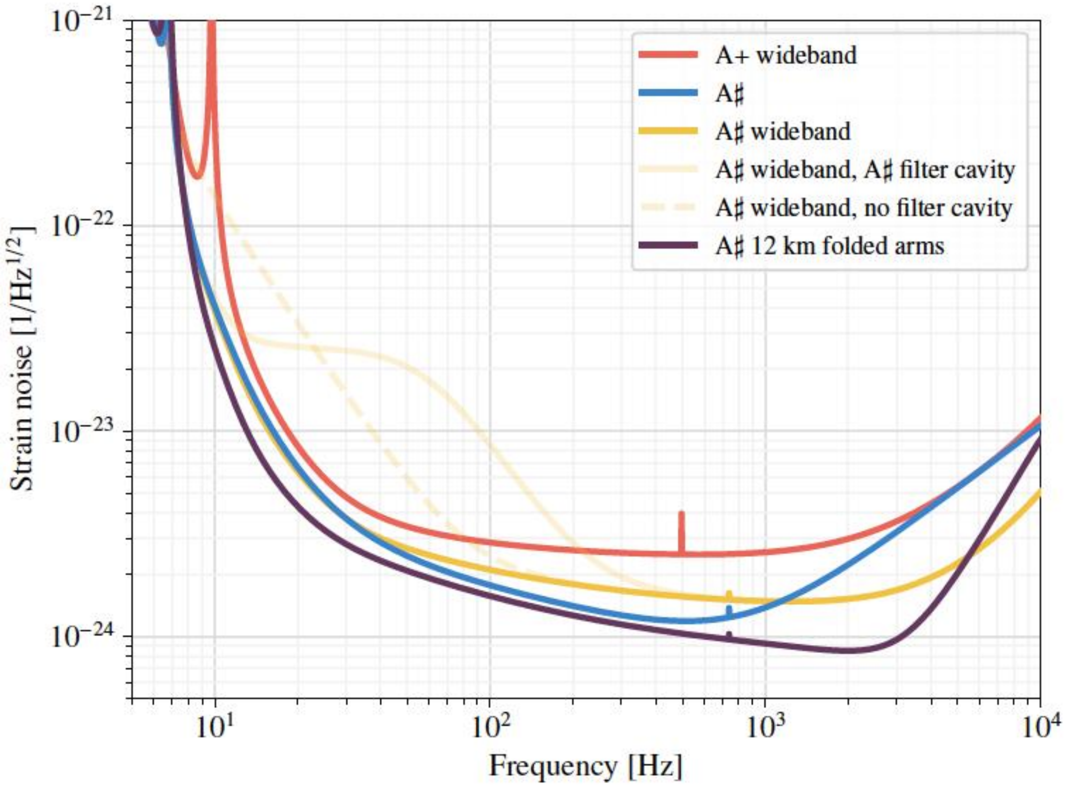
Given BNS rate
21.6 – 296 Gpc-1yr-1
TM1
DD2
SFHo
SLy
APR4
$N_{SNR} > 5$ per year
Maximum SNR
10^2
10^1
10^0
10^{-1}
10^{-2}
A+
NEMO
ET
CE-20 km
CE-40 km
New Detector

Related developments

Post-O5 upgrade: Adopting LIGO-HF Concept

High frequency upgrades

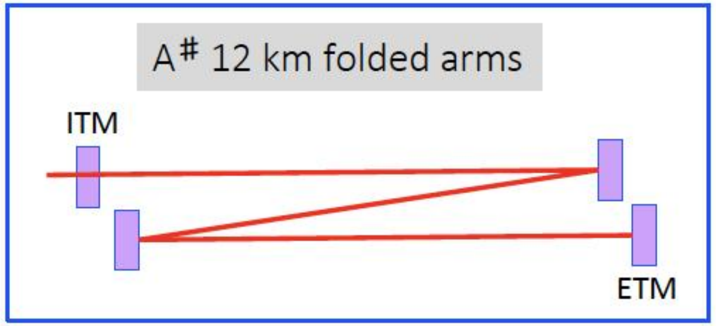
D.Ghanapathy et al., PRD **103** 022002 (2021)



Post-O5 upgrade: starts around 2028

$A^{\#}$ & A+ wideband:

- More signal recycling to further widen the arm cavities
- Filter cavity re-optimization
- At the expense of sensitivity at mid-frequencies, by ~1.5x



D Martynov et al., PRD **99** 102004 (2019)

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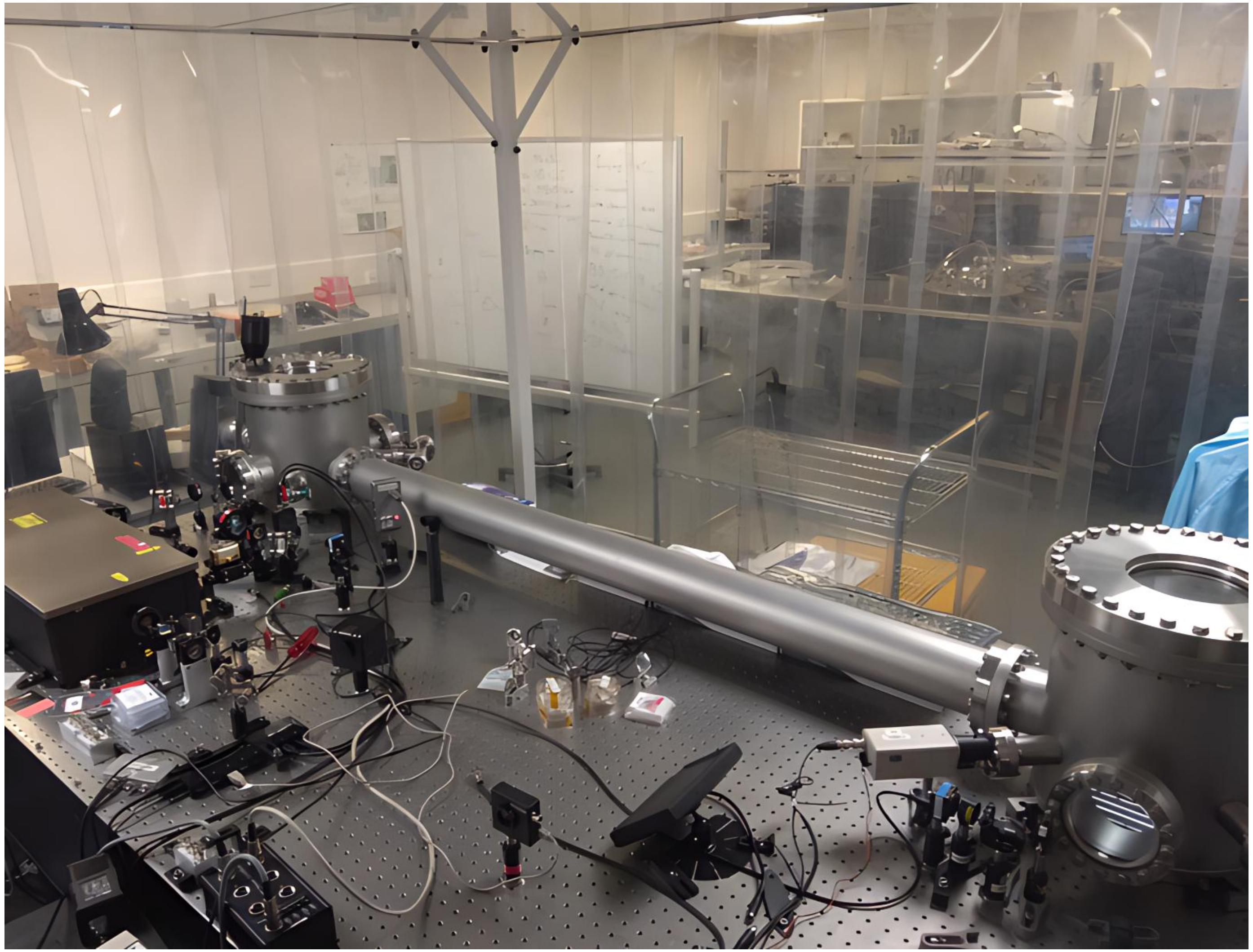
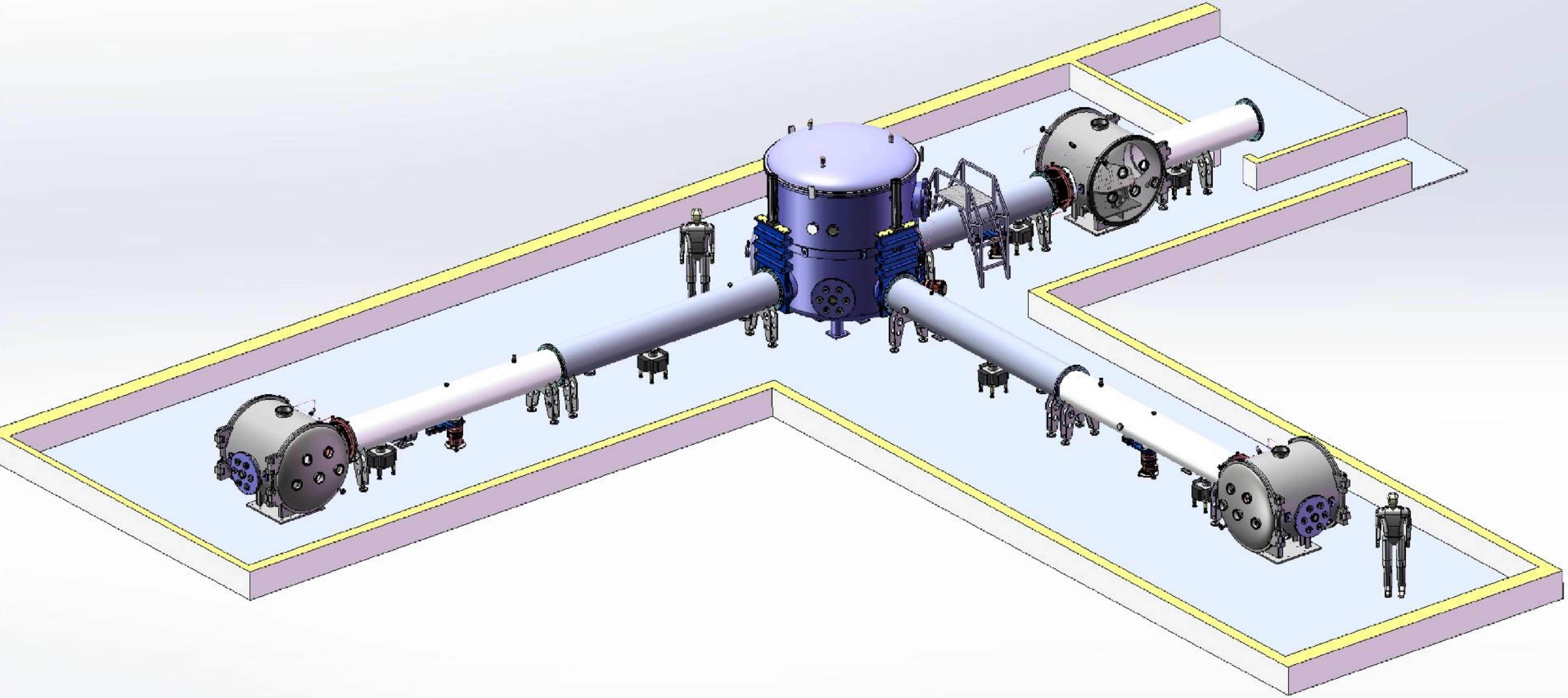
P. Fritschel *et al.*, *Report from the LSC Post-O5 Study Group*, LIGO-DCC: T2200287 (2022)

Tabletop Experiment



J. Smetana, A. Dmitriev, C. Zhao, H. Miao, and D. Martynov, *Design of a tabletop interferometer with quantum amplification*, Phys. Rev. A 107, 043701 (2023)

Beijing Normal University 12m Prototype



Credit： BNU team

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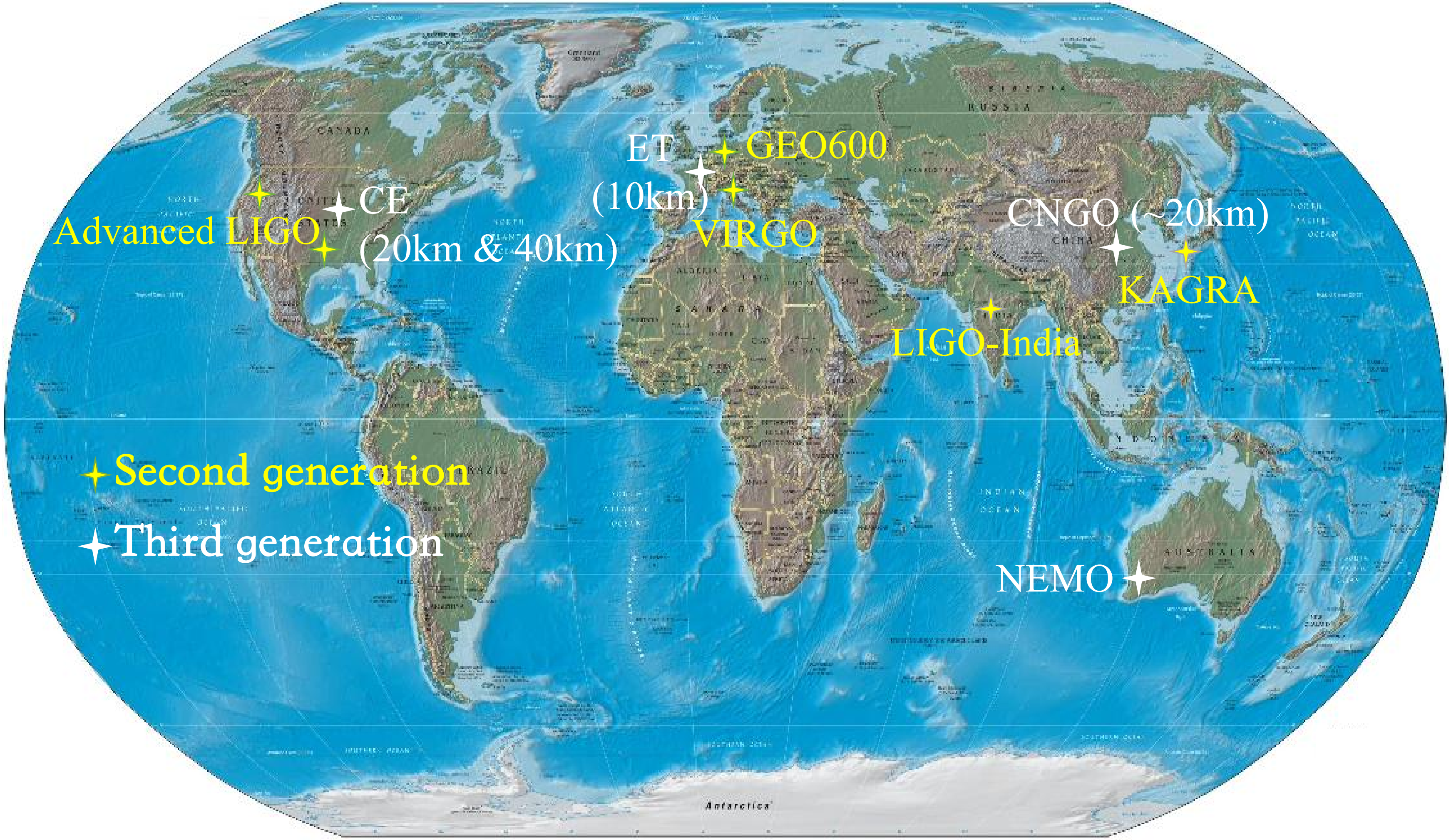
Not-So-Near-Term Vision



CNGO: Colliding Neutron-star Gravitational-wave Observatory

2nd Path to kHz GW Astronomy Workshop @ Tsinghua

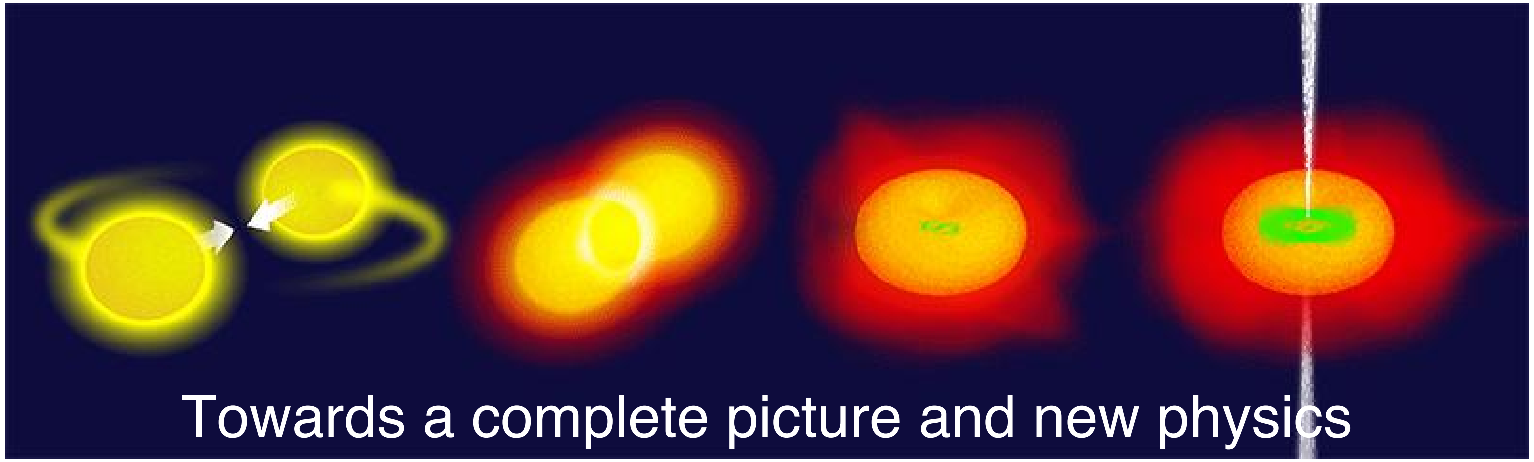
Summary

❖ Binary neutron star merger is a cosmic hadron collider.

❖ State-of-the-art simulations predict robust spectral features for post-merger GWs.

❖ kHz detector sensitivity is limited by noise of quantum origin.

❖ Design optimal for kHz signals has been found and experimental efforts are ongoing.



Thank you!