Astrofisica Nucleare e Subnucleare

Memory-triggered supernova neutrino detection

Journal Club #4

Memory-triggered supernova neutrino detection

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We demonstrate that observations of the gravitational memory from core collapse supernovae at future Deci-Hz interferometers enable time-triggered searches of supernova neutrinos at Mt-scale detectors. Achieving a sensitivity to characteristic strains of at least $\sim 10^{-25}$ at $f \simeq 0.3$ Hz – e.g., by improving the noise of DECIGO by one order of magnitude – will allow robust time triggers for supernovae at distances $D \sim 40 - 300$ Mpc, resulting in a nearly background-free sample of $\sim 3 - 70$ neutrino events per Mt per decade of operation. This sample would bridge the sensitivity gap between rare galactic supernova bursts and the cosmological diffuse supernova neutrino background, allowing detailed studies of the neutrino emission of supernovae in the local Universe.

https://arxiv.org/abs/2110.14657

Introduction

- In this paper, we propose a new time-triggered method to detect supernova neutrinos, which is potentially sensitive to supernovae up to ~ 100 Mpc. The time trigger is the observation of the gravitational memory signal caused by the neutrino emission itself.
- The memory is a non-oscillatory, permanent distortion of the local space time due to the anisotropic emission of matter or energy by a distant source. The memory due to neutrino emission by a supernova at distance r has characteristic strain hc ~ 10−23 − 10−21(10 kpc/r) and frequencies in the Deci-Hz band, f ~ 0.1 − 3 Hz [23–29].
- The memory develops ~ 0.1 s from the start of the neutrino emission, thus being an ideal time-trigger.
- Next generation powerful Deci-Hz GW detectors, like the Deci-hertz Interferometer Gravitational wave Observatory (DECIGO) [30–33] and the Big Bang Observer (BBO) [31] will provide robust triggers for supernovae at 10 Mpc and beyond [34].
- These would result in a nearly pure sample of ~ 10 − 100 supernova neutrino events from the local universe within a few decades; see our summary figure, fig.1. Here we illustrate our proposed methodology and
- its physics potential.

Number of triggered neutrinos

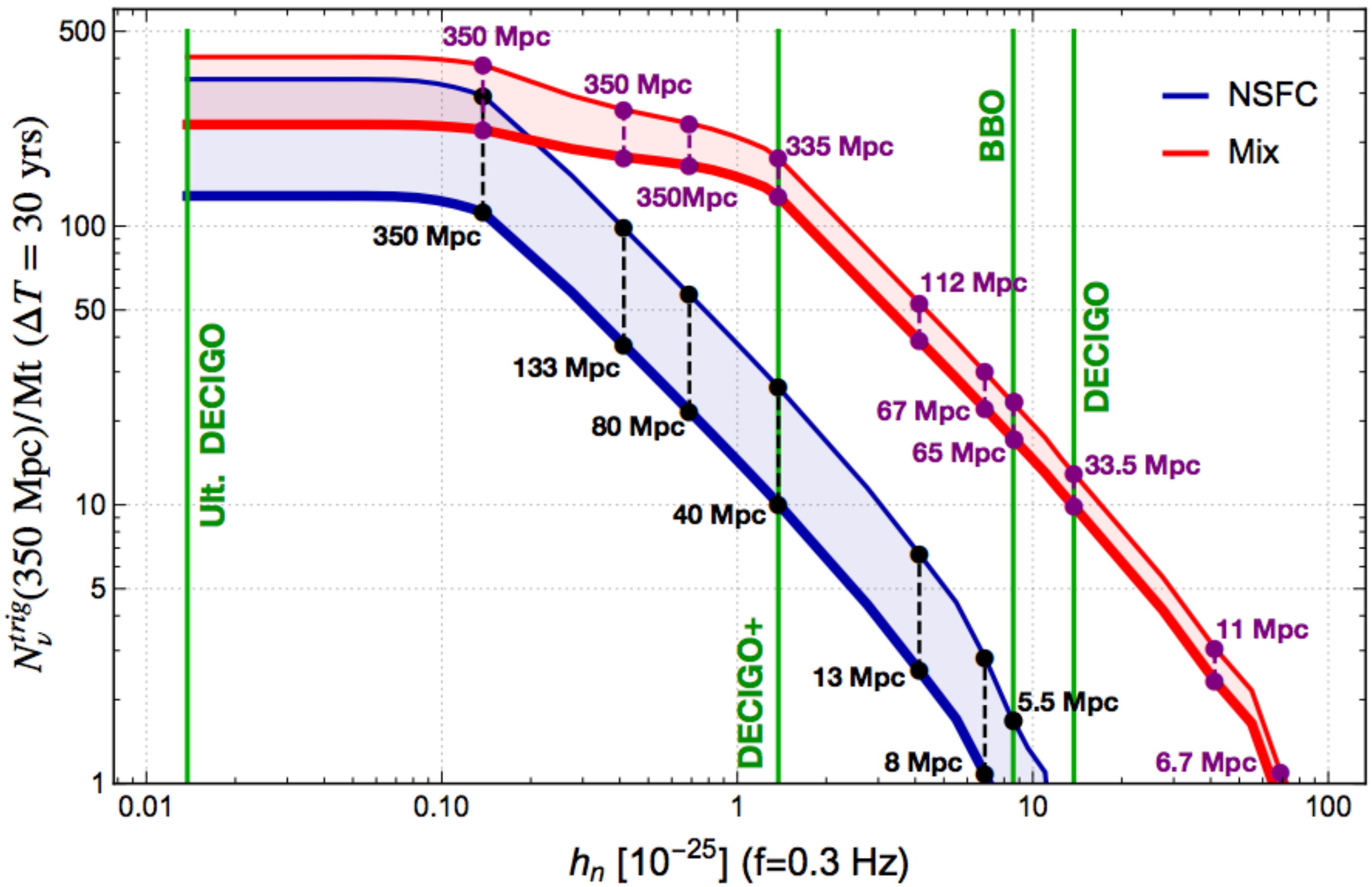


Fig. 1

Characteristic gravitational memory strain

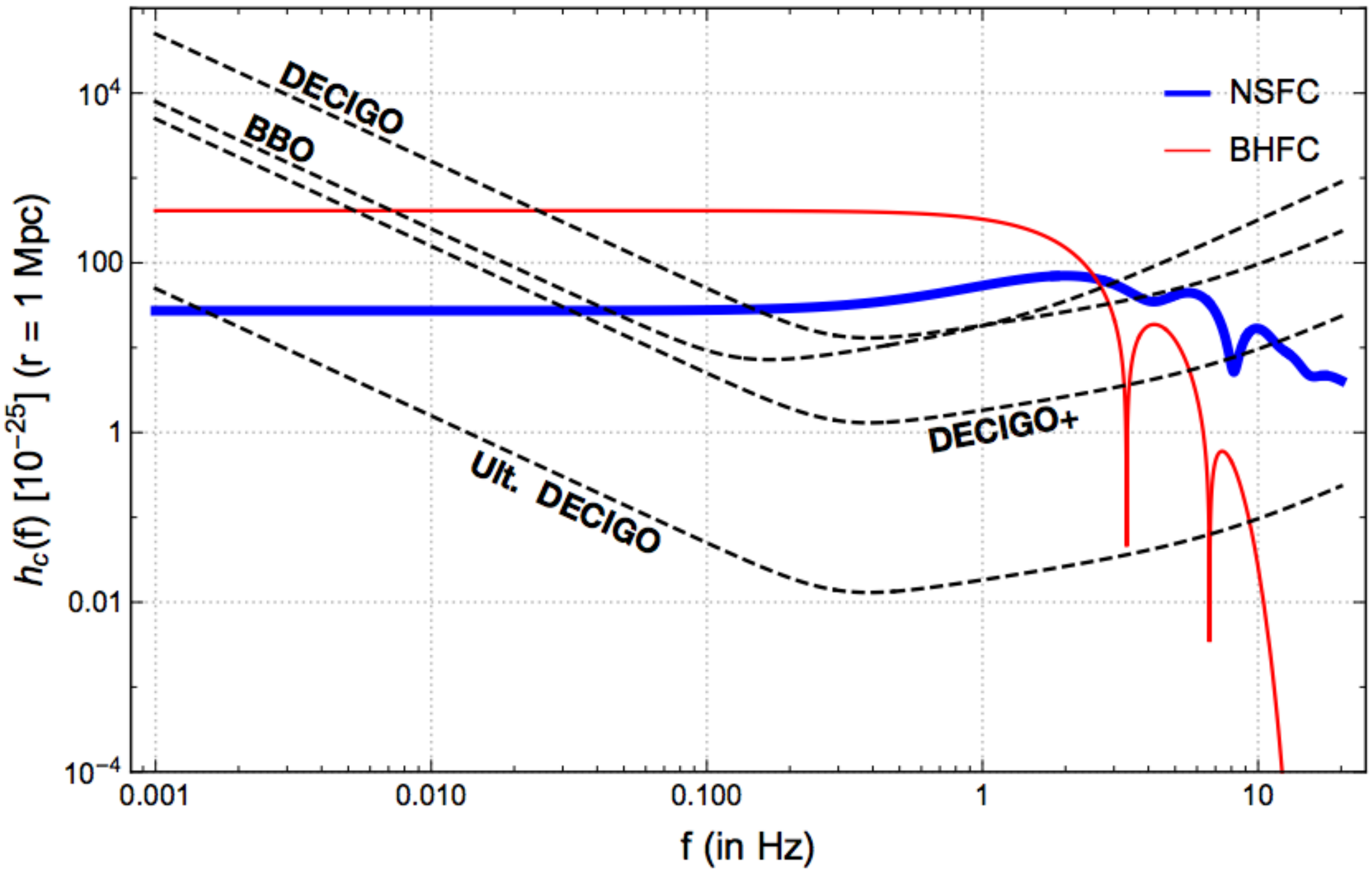


Fig. 2

Detection probabilities for a memory signal

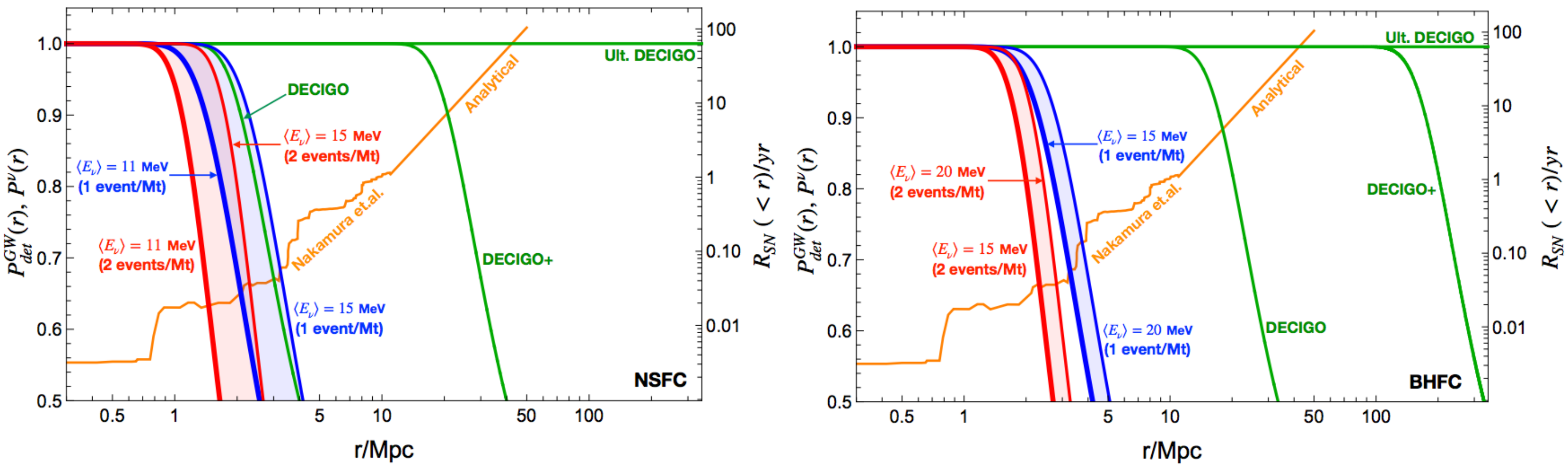


Fig. 3

Number of background events and of memory-triggered neutrino events

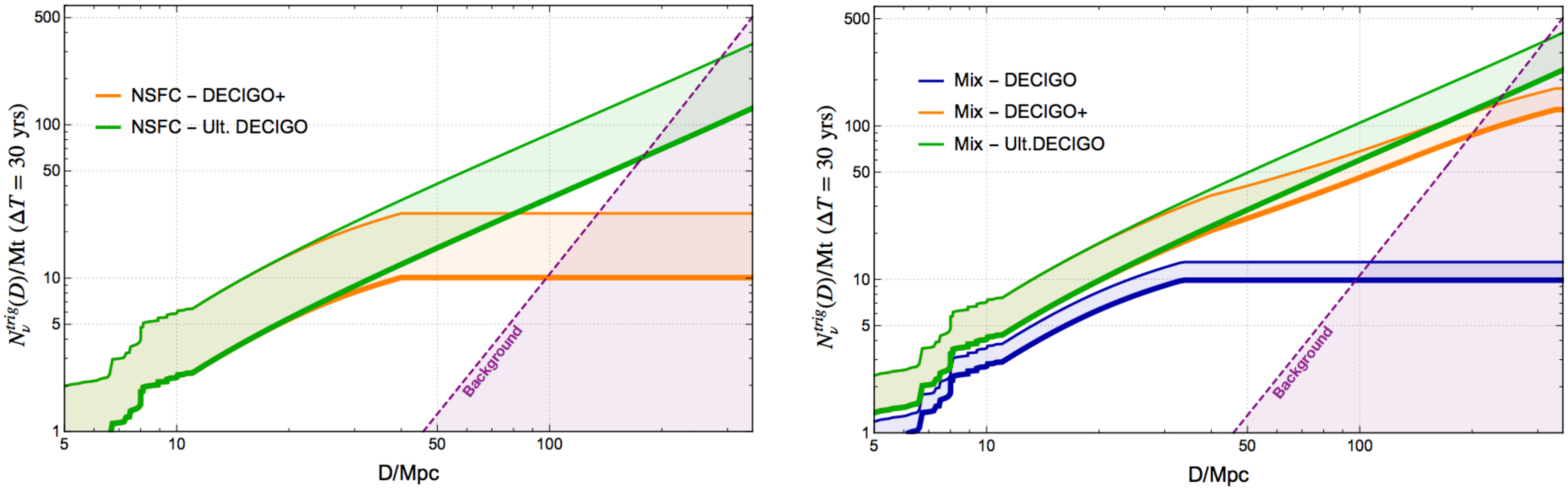


Fig. 4

Conclusions

- Summarizing, we have described a new multimessenger approach to core collapse supernovae, where a time triggered search of supernova neutrinos is enabled by observing the gravitational memory caused by the neutrinos themselves.
- This scenario could be realized a few decades from now, when powerful Deci-Hz interferometers (noise $h_n \leq 10^{-25}$) and Mt-scale neutrino detectors start operating.
- For optimistic parameters, DECIGO and Hyper-Kamiokande (mass M = 0.260 Mt) might already achieve a low statistics observation. This approach will also enable joint analyses of neutrino, GW and light curves of CCSNe in local universe.
- Our proposed method will deliver a sample of neutrino events from supernovae in the local universe, from which the main neutrino properties - i.e, the (population-averaged) energy spectra and time profiles - will be measured.

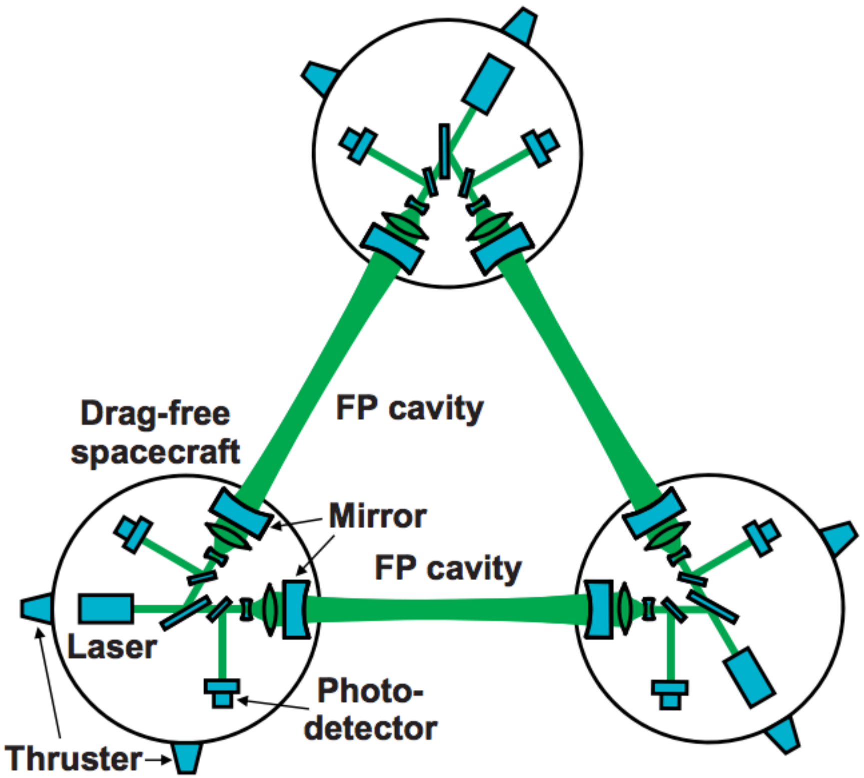
Conclusions

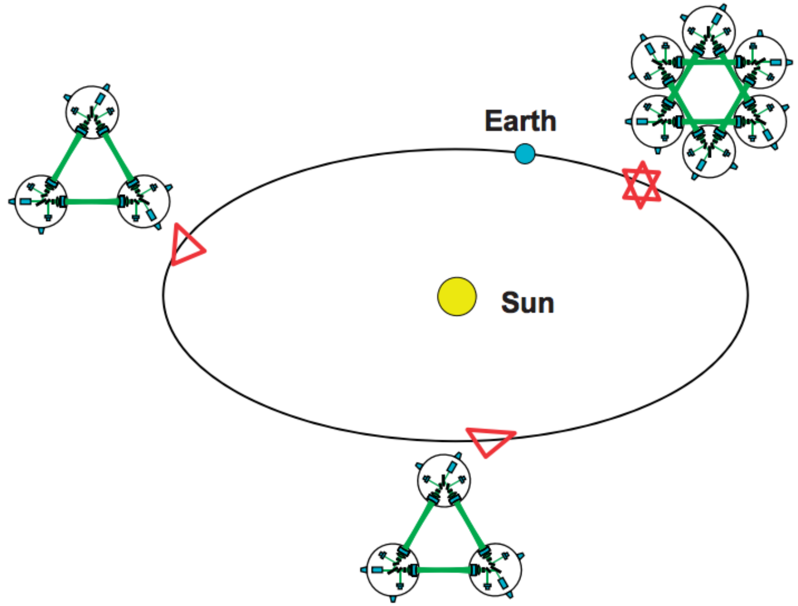
- These can then be compared to the same quantities from (1) SN 1987A, to measure the deviation between SN1987A and an average local supernova (the same exercise can be done for a future nearby supernova burst, if it occurs); (2) the DSNB, to distinguish the contributions to the DSNB by CCSNe in the distant universe and by other transients (e.g. binary mergers).
- The comparison between cosmological and local contributions to the DSNB will test hypotheses of how the supernova progenitor population evolves with the distance. Even within the local-neutrino sample, one could test the evolution with distance, if the latter is estimated for each supernova using multi-messenger observations (e.g., the amplitude of the memory signal and astronomical imaging).
- Correlating memory and neutrino data might reveal two distinct populations, like those described here (NSFC and BHFC), which could be statistically separated. For example, events having a relatively large neutrino memory time separation (bigger than 1 s, as black hole formation typically occur within 1 s, cutting on the neutrino luminosity) and(or) followed by electromagnetic (EM) signals of a CCSN could be attributed to NSFC.

Conclusions

- The possibility to study such sub-population individually is unique of this local-collapses neutrino sample.
- Additionally, our method provides a unique chance to jointly analyze neutrino and follow-up EM signals from the same NSFC. Although only 1 event would be detected from a specific NSFC, it can help to determine the time when the core of a NSFC collapses and the shock is formed. Such estimation would be relatively precise, considering that the neutrino burst from a NSFC only lasts for 10 s. A supernova EM signal is delayed relative to the neutrinos, by at least the time it takes the shock to propagate through the envelope, typically hours.
- Measuring this time delay will provide a crucial confirmation and can test the variation of the CCSNe explosion mechanism.
- To conclude, we have demonstrated that the interplay between neutrino detectors and sub-Hz GW observatories will open a new path to studying supernova neutrinos.
- Although several decades may pass before the first results become available, the work of designing the next generation of experiments is well under way, and we hope that our work will contribute to its progress.

DECIGO





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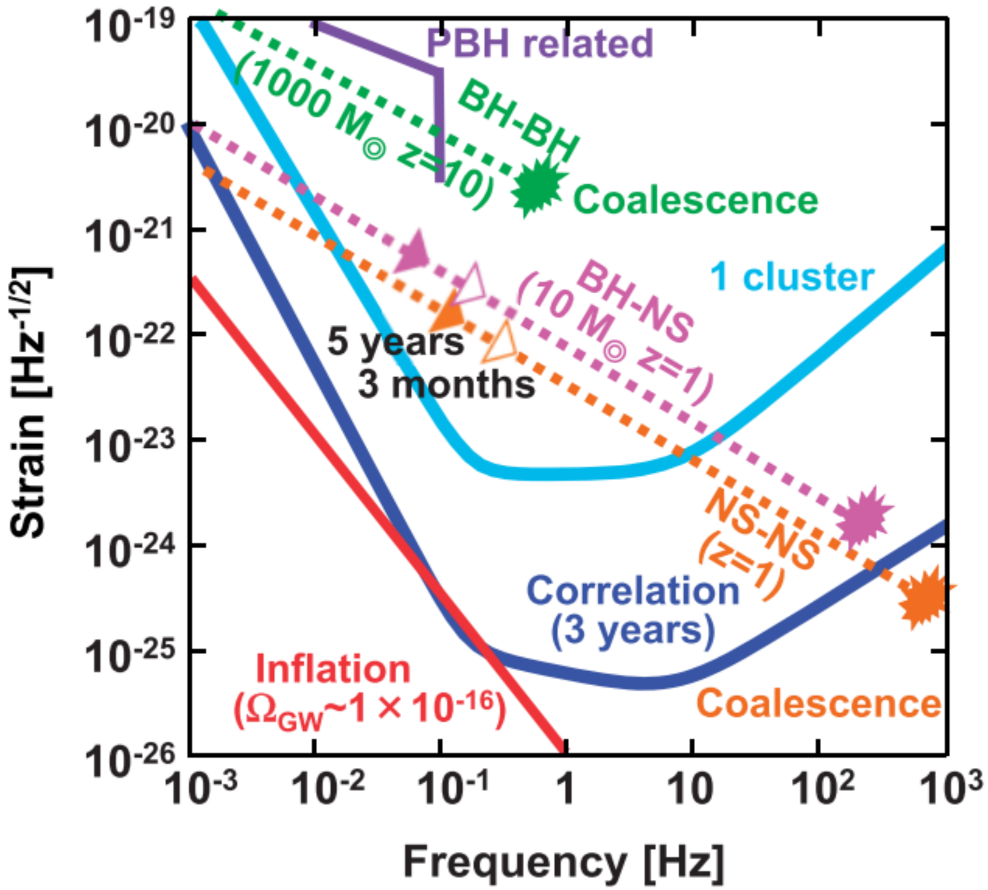
DECIGO



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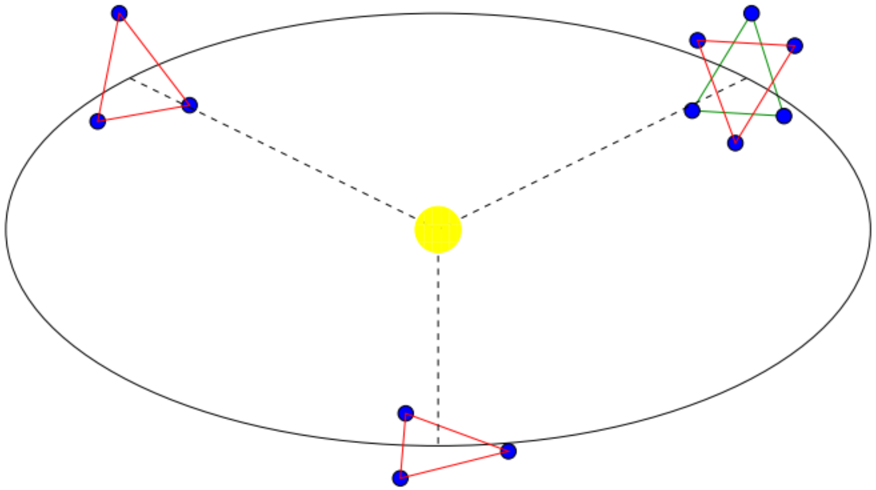
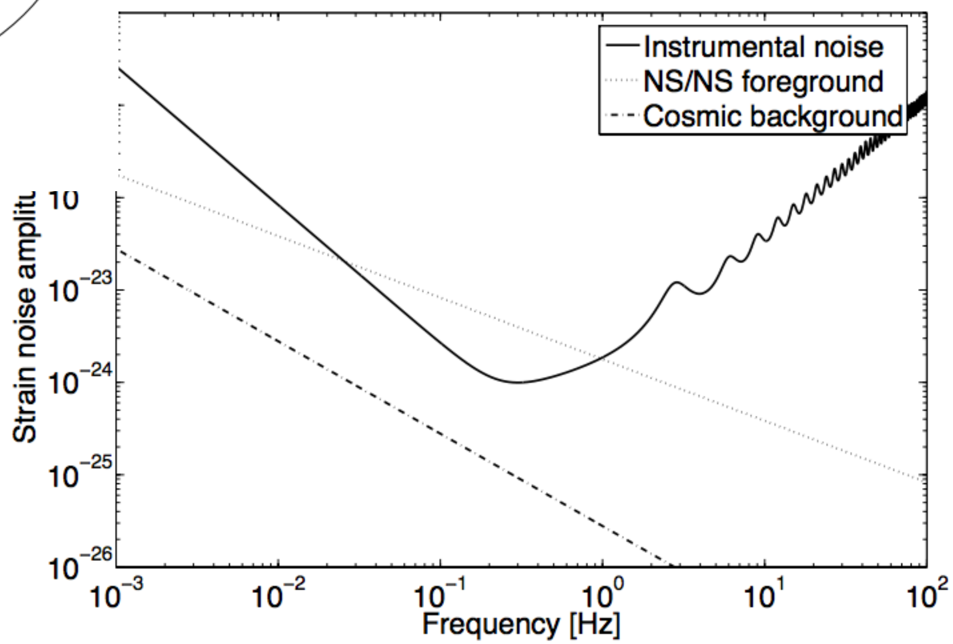
BBO





https://arxiv.org/pdf/0906.3752.pdf