Fast localization with a hierarchical network of gravitational wave detectors

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Introduction

We present expected fast sky localisation of coalescing binaries with a hierarchical search using three gravitational wave (GW) detectors, HLV (Hanford/Livingston/Virgo).

A hierarchical search can be used with a network of GW detectors with varying sensitivities, and is aimed at making effective use of the least sensitive detector's information. Here we demonstrate the sky localisation using a hierarchical search with the two higher sensitivity LIGO detectors and the less sensitive Virgo detector, using simulated signals.

Hierarchical network

For precise source localization:
Triple (or more) coincidences

At the beginning:
Detectors with different sensitivity

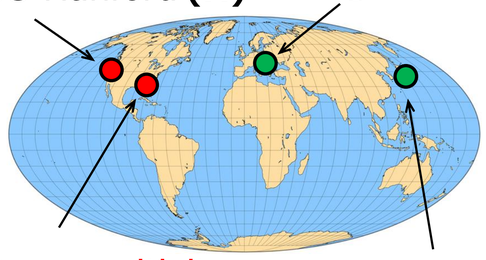
For getting more coincidences:
Set a lower threshold, as long as not too many background triggers

⇨ ***Analyze hierarchically!***

How to analyze:

Higher sensitivity
LIGO Hanford **(H)**

Lower sensitivity
Virgo (V)



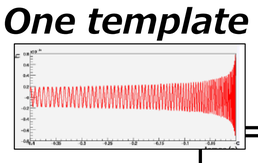
Higher sensitivity
LIGO Livingston **(L)**

Lower sensitivity
KAGRA (K)

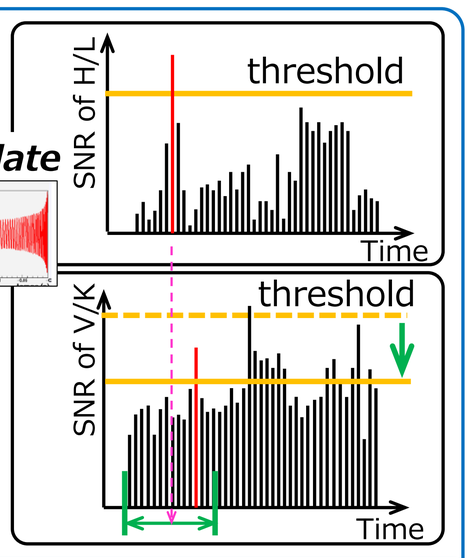
(At the beginning)

Higher sensitivity detectors ***sub network detects candidate event.***

One template



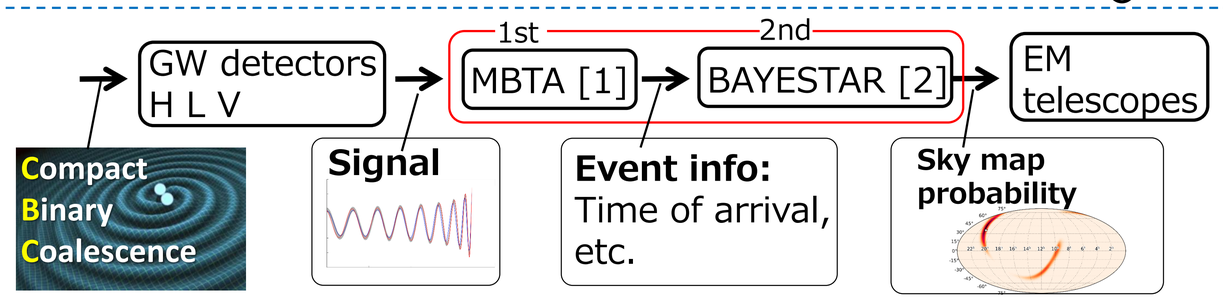
Less sensitive detectors are added into network
1. with lower SNR threshold
2. using same parameters &
3. a small window around time of double coincidences.



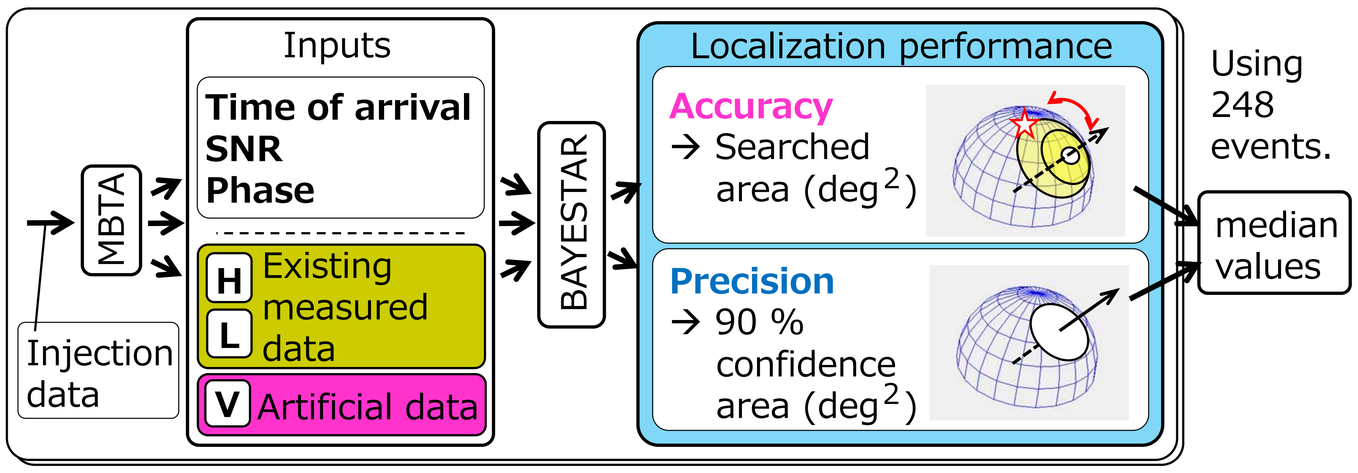
→ How does this approach improve the localization?

Calculation setup

Assumptions:
Higher sensitivity: HL → 70 Mpc, Lower sensitivity: V (for 1.4–1.4 $M_\odot$ BNS range)



Calculation main flow:

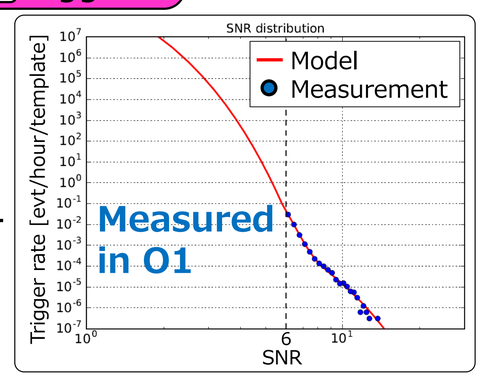


Generating & mixing artificial V triggers

1. Generating V triggers

V_r : V trigger based on random parameters

SNR = random following measurement
Time = t_{H1} or t_{L1} + random [-35ms:35ms]
Phase = random [0:2π]



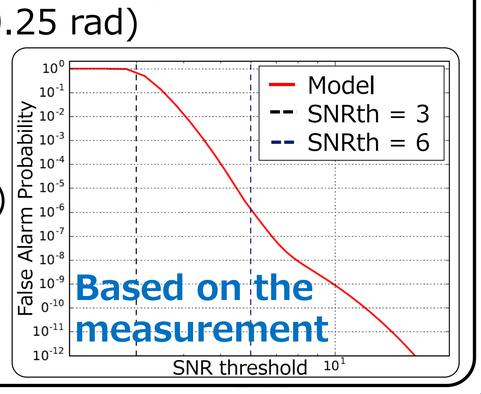
V_i : V trigger based on injection parameters

SNR = metadata + Gauss(0,1)
Time = metadata + Gauss(0,0.66 ms*$\frac{6}{\mathrm{SNR}}$)
Phase = metadata + Gauss(0,0.25 rad)

2. Mixing HLV triggers

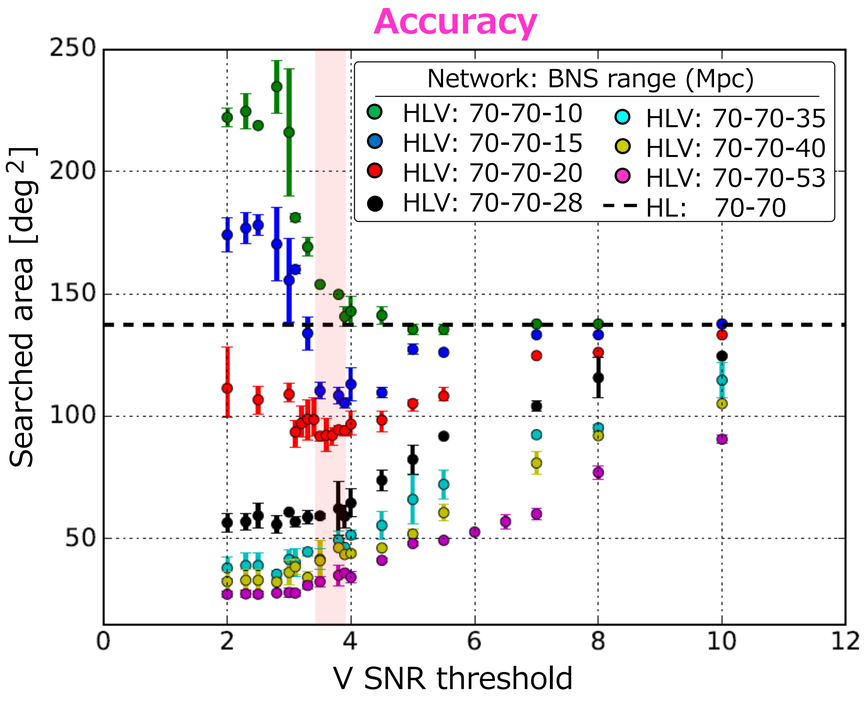
p = random [0:1]
FAP = *FAP*(*SNR*) or *FAP*(SNRth)

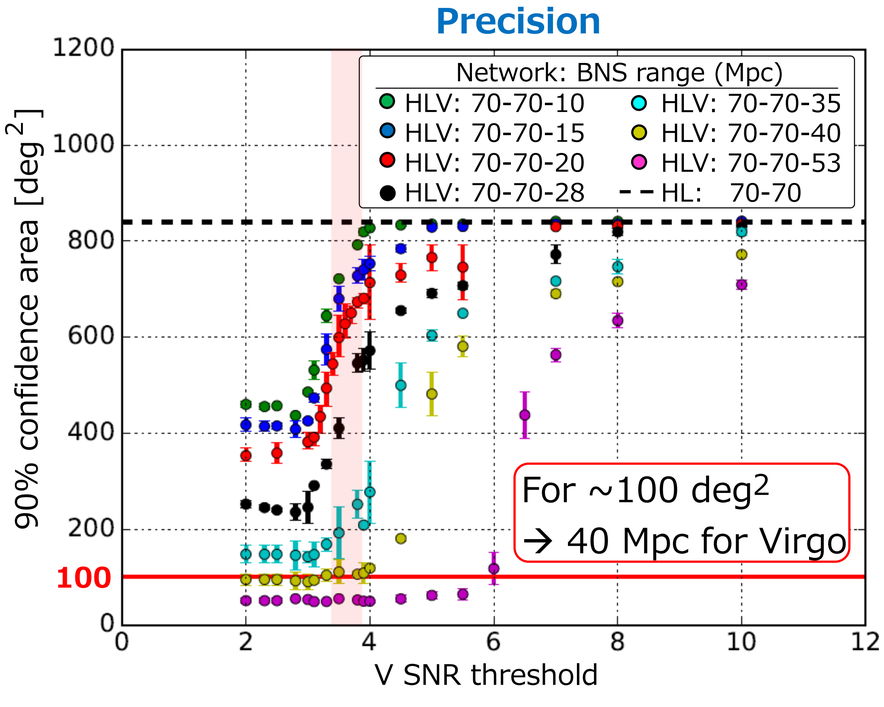
p<*FAP* → HLV$_r$
p>*FAP* & *SNR*>SNRth → HLV$_i$
p>*FAP* & *SNR*<SNRth → HL



Expected performance with HLV hierarchical network

Sky localization performance, when SNR threshold for HL is 5:
→ Optimal SNR threshold for V detector? → Dependence of V detector's sensitivity?





Conclusion:

The hierarchical network improves:

1. localization accuracy

effectively at V SNRth ~3.5, if V range is greater than 15 Mpc

2. localization precision

at any sensitivity.

HLV-hierarchical network using HL: 70 Mpc, SNRth = 5 and V : >15 Mpc, SNRth ~3.5 effectively improves the sky localization as shown by the coloured bands.

Summary

1. We investigated the expected fast localization performance with a hierarchical network using HLV.
2. We demonstrated that the hierarchical network effectively improved the accuracy & precision when V threshold is set to ~3.5, if BNS range of V detector is greater than 15 Mpc.
3. The hierarchical search will be most useful when adding new detectors, which are less sensitive as they are undergoing commissioning, to the network.

Future work:

1. **Investigate the localization with HLVK hierarchical network**
2. **Implement in online analysis**

References : [1] T. Adams et. al., Class. Quant. Grav. 33 (2016) [2] L. P. Singer, L. R. Price, Phys. Rev. D **93**, 024013 (2016)