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Test of scalar-tensor gravity theory from observations of gravitational wave bursts with advanced detector network

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Search for scalar gravitational waves

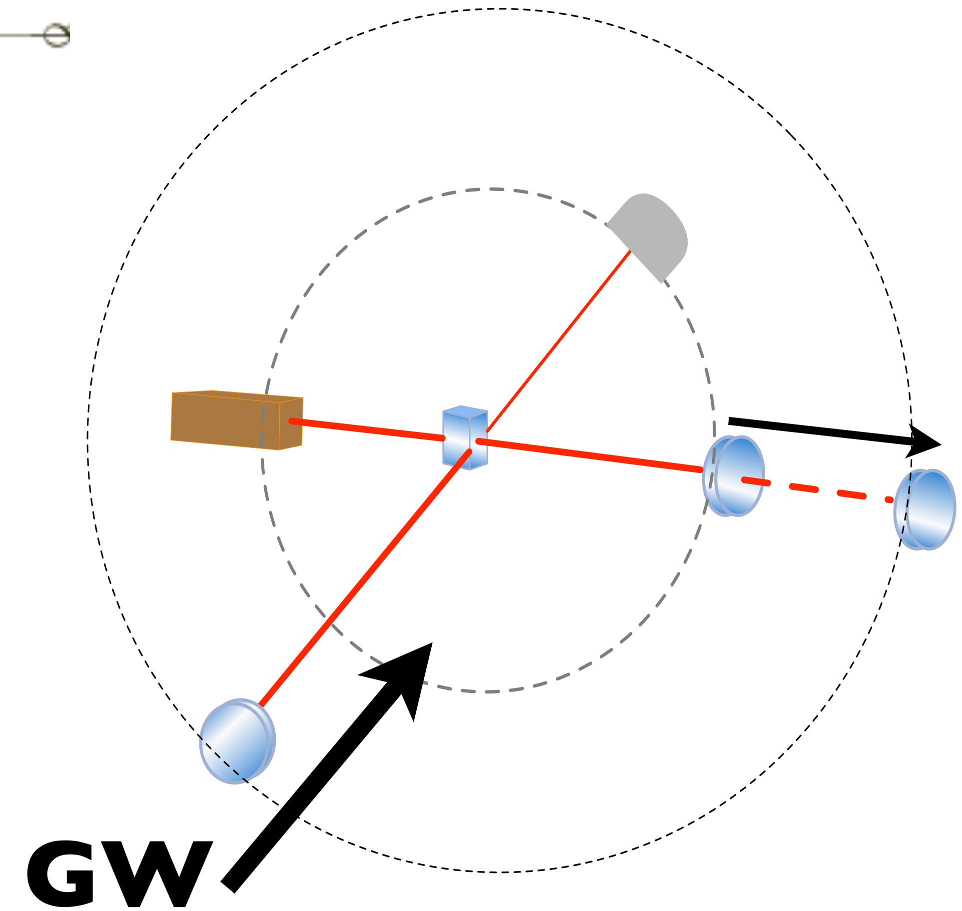
- Testing relativistic gravity theory is important for fundamental physics and cosmology e.g. dark matter, dark energy, accelerating the Universe.
- One of plausible gravity theories is scalar-tensor theory. Significant difference from the general relativity is the existence of a scalar field which is connected with the gravity field with coupling parameters, and a resulting scalar gravitational wave. Brans-Dicke theory is famous scalar-tensor theory which has a coupling parameter ω_{BD}.
- Tensor GW search might miss some type of sources, e.g. highly spherical core collapse if scalar-tensor theory is correct. In this sense, search for SGW is complementary to current GW search.
- This talk will focus on search for SGW from Galactic spherical core collapses in Brans-Dicke theory.

Antenna pattern for scalar mode

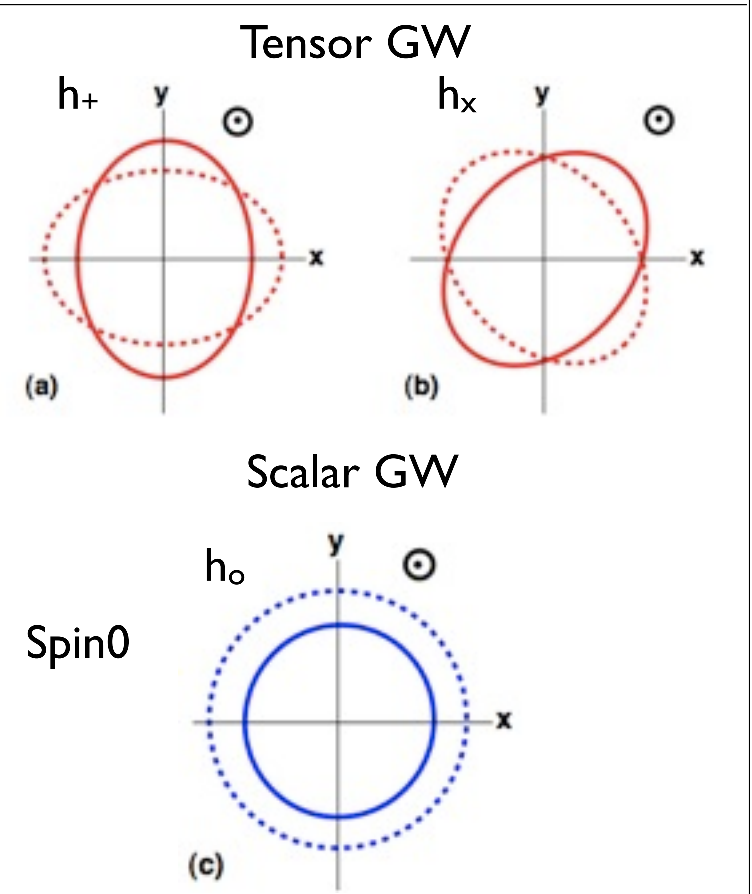
Antenna pattern function as a function of sky position (θ,Φ) is written as

$$
\begin{aligned}
F_{+}(\hat{\Omega}) &= \frac{1}{2}(1+\cos^2\theta)\cos 2\phi \\
F_{\times}(\hat{\Omega}) &= \cos\theta\sin 2\phi \\
F_{\circ}(\hat{\Omega}) &= -\sin^2\theta\cos 2\phi .
\end{aligned}
$$

M.Tobar etal(1999), M. Maggiore etal(2000), K.Nakao etal(2001)

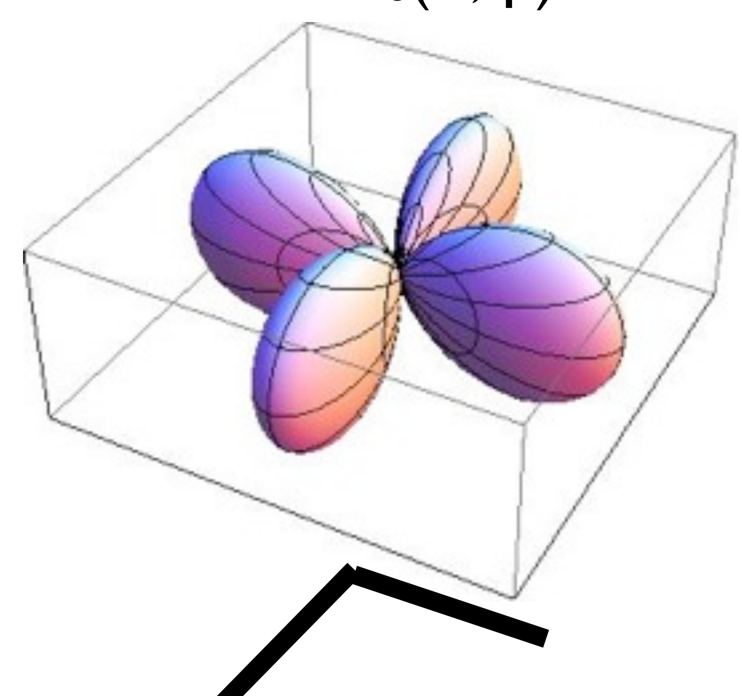


Polarization of tensor, scalar gravitational wave



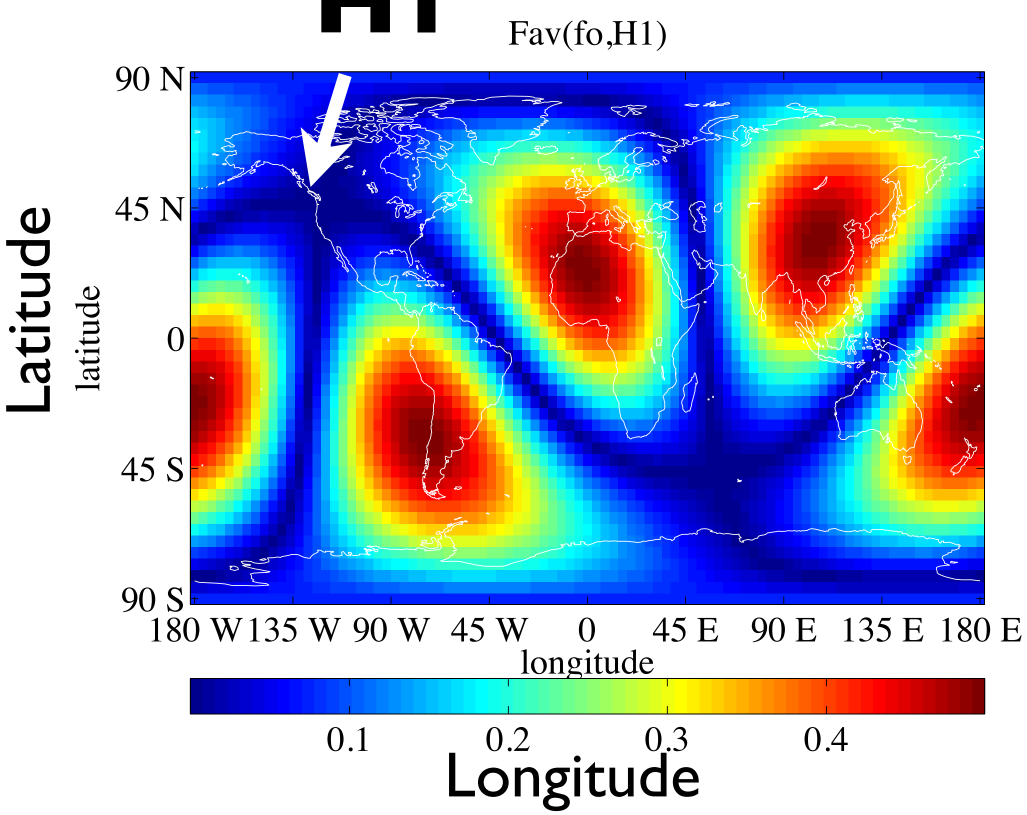
C.Will, Living Review (2006)

$F_o(\vartheta,\varphi)$

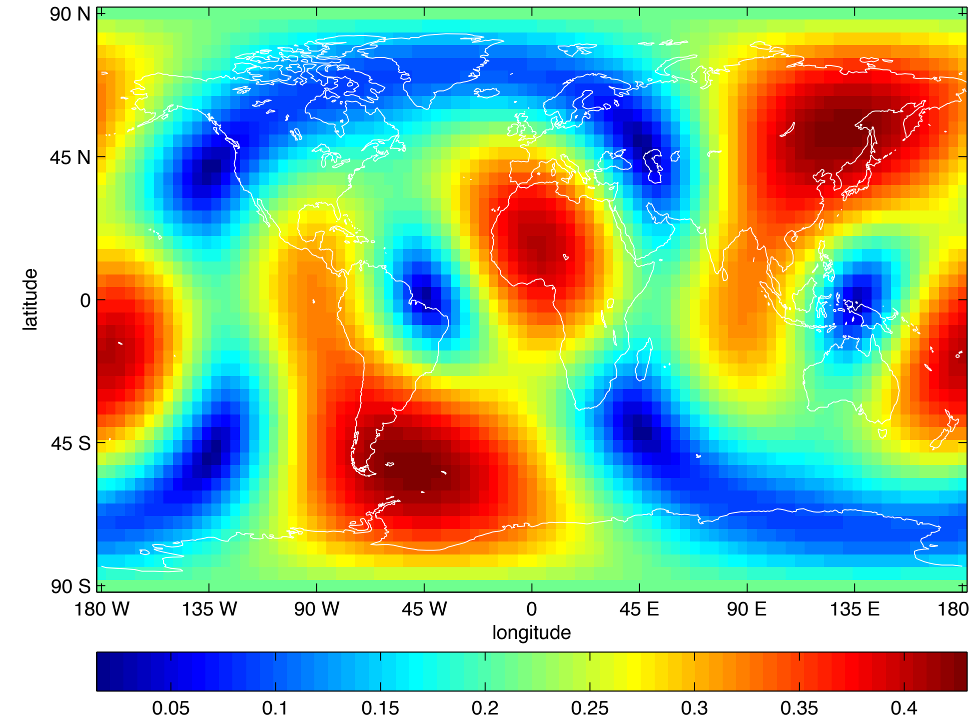


Antenna pattern sky-map of scalar mode

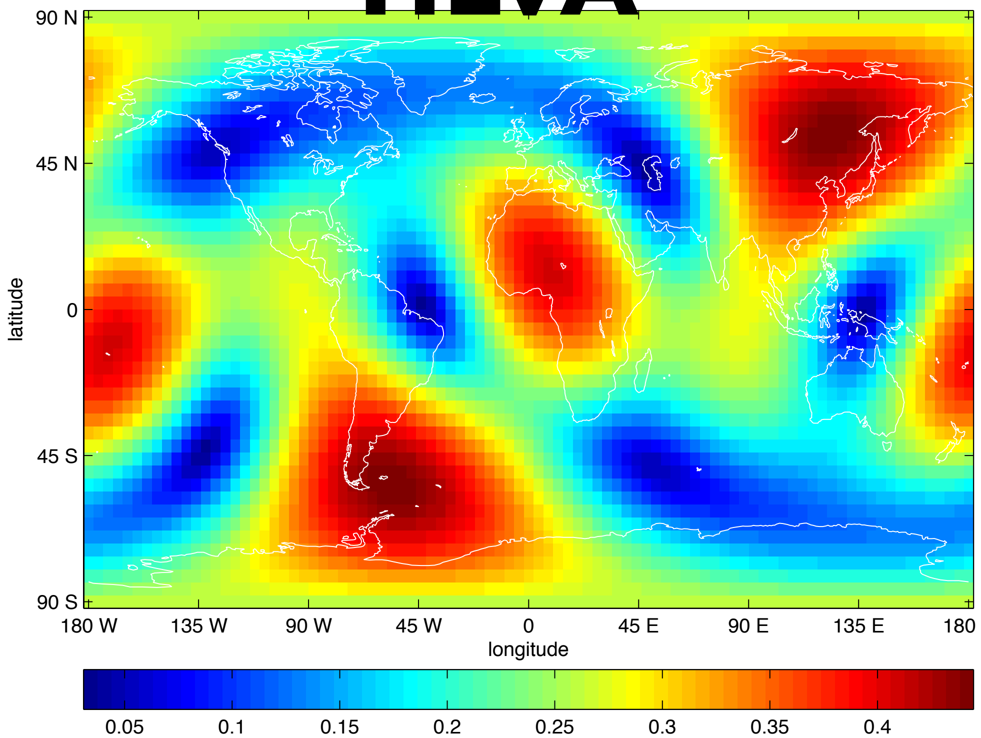
H1



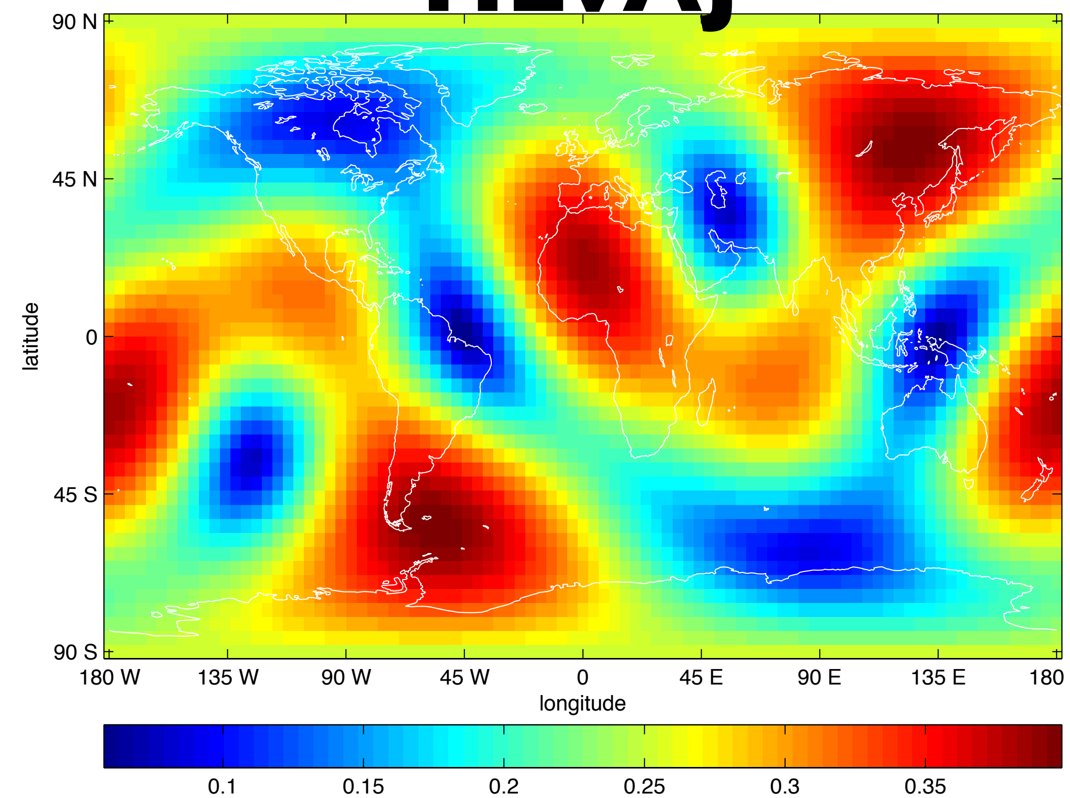
HLV



HLVA



HLVAJ



Coherent network analysis

- **Coherent network analysis can extract scalar gravitational wave with more than 3 world-wide detectors. This approach combines data taking account of the sky position (ϑ,φ), arrival time difference τ(ϑ,φ) coherently, and calculates all polarization components at a certain direction of the sky which is most likely.**

Mathematical expression of the coherent network analysis

Expression of d-detectors can be taken as

$$\begin{bmatrix} x_1 \\ \vdots \\ x_d \end{bmatrix} = \begin{bmatrix} F_{1+} & F_{1\times} & F_{1\circ} \\ \vdots & \vdots & \vdots \\ F_{d+} & F_{d\times} & F_{d\circ} \end{bmatrix} \begin{bmatrix} h_+ \\ h_\times \\ h_\circ \end{bmatrix} + \begin{bmatrix} n_1 \\ \vdots \\ n_d \end{bmatrix}$$

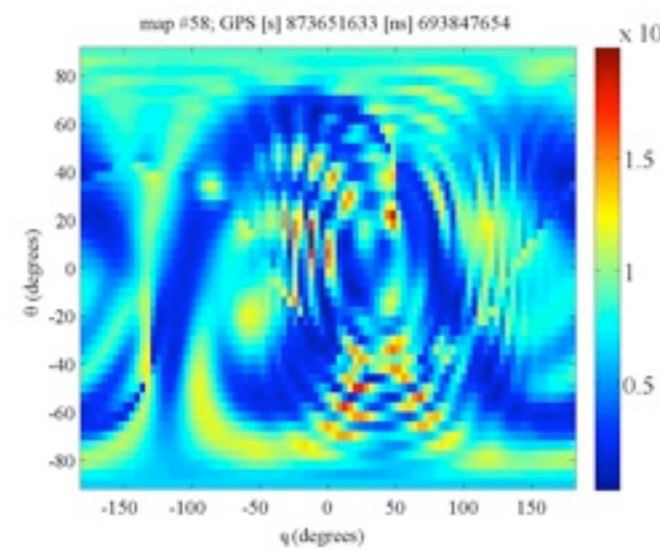
The reconstruction of a gravitational wave is an inverse problem.
Maximum likelihood method to solve the inverse problem:

$$L[\boldsymbol{h}] := \| \boldsymbol{x} - \boldsymbol{F}\boldsymbol{h} \|^2$$

Changing sky position (ϑ,φ), time difference τ(ϑ,φ).
The mathematical formula of the reconstructed scalar gravitational wave is

$$\begin{aligned} h_\circ &= \frac{1}{\det(\boldsymbol{M})}(((F_+ \times F_\times)\cdot(F_\times \times F_\circ))\cdot F_+ \\ &- ((F_+ \times F_\times)\cdot(F_+ \times F_\circ))\cdot F_\times \\ &+ ((F_+ \times F_\times)\cdot(F_+ \times F_\times))\cdot F_\circ)\cdot \boldsymbol{x} \end{aligned}$$

Likelihood residual sky-map



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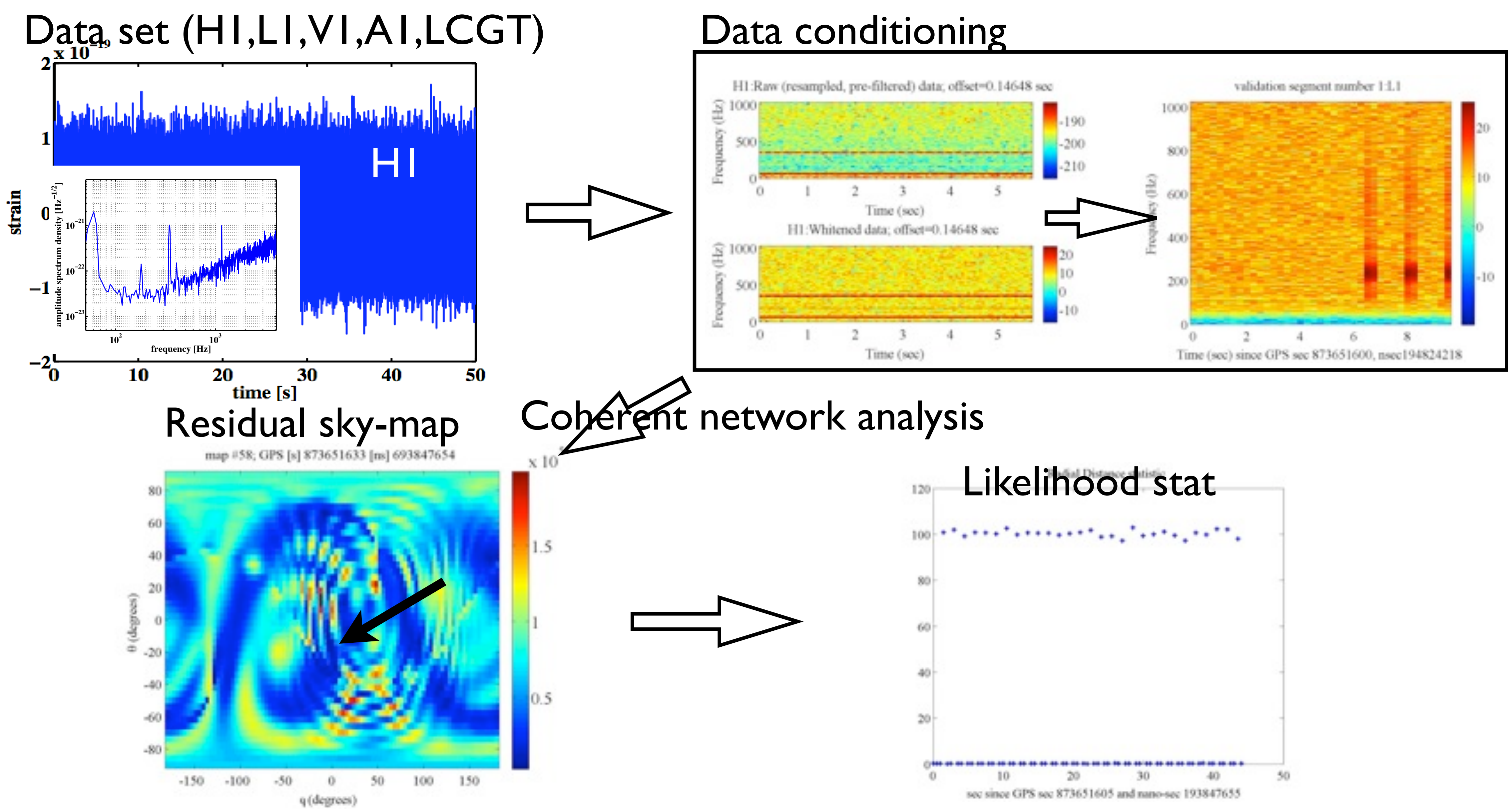
Scalar pipeline

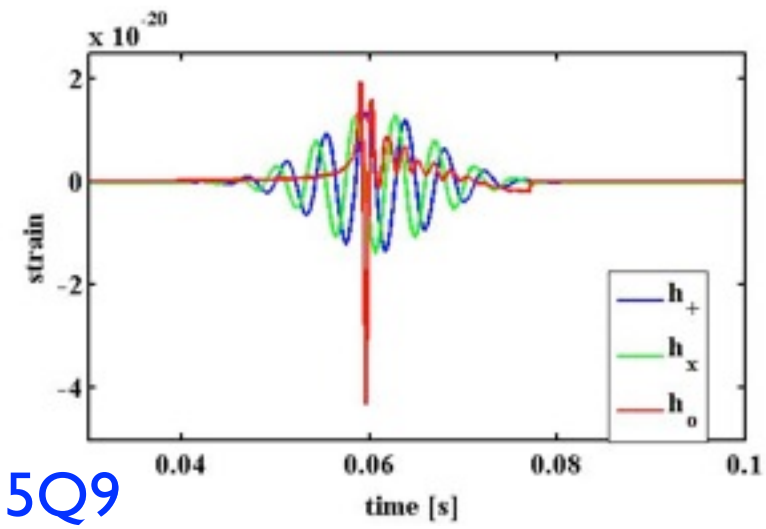
- **Full featured coherent network analysis pipeline(Data conditioning, detection stat., Veto analysis)**
- **One can apply the pipeline to H1,L1,V1,A1,LCGT**
- **Analysis result is output by a Web-based event display.**



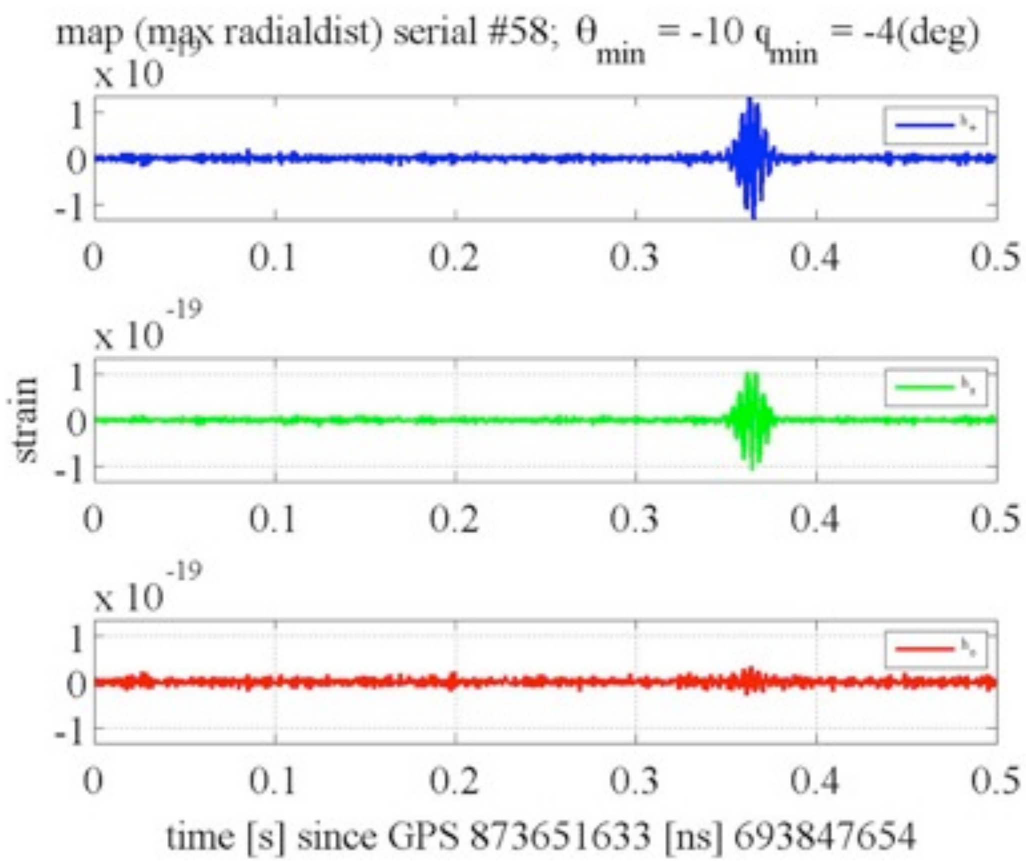
Demonstration of pol. reconstruction

Reconstruction of h_+, $h_\times$, $h_\circ$

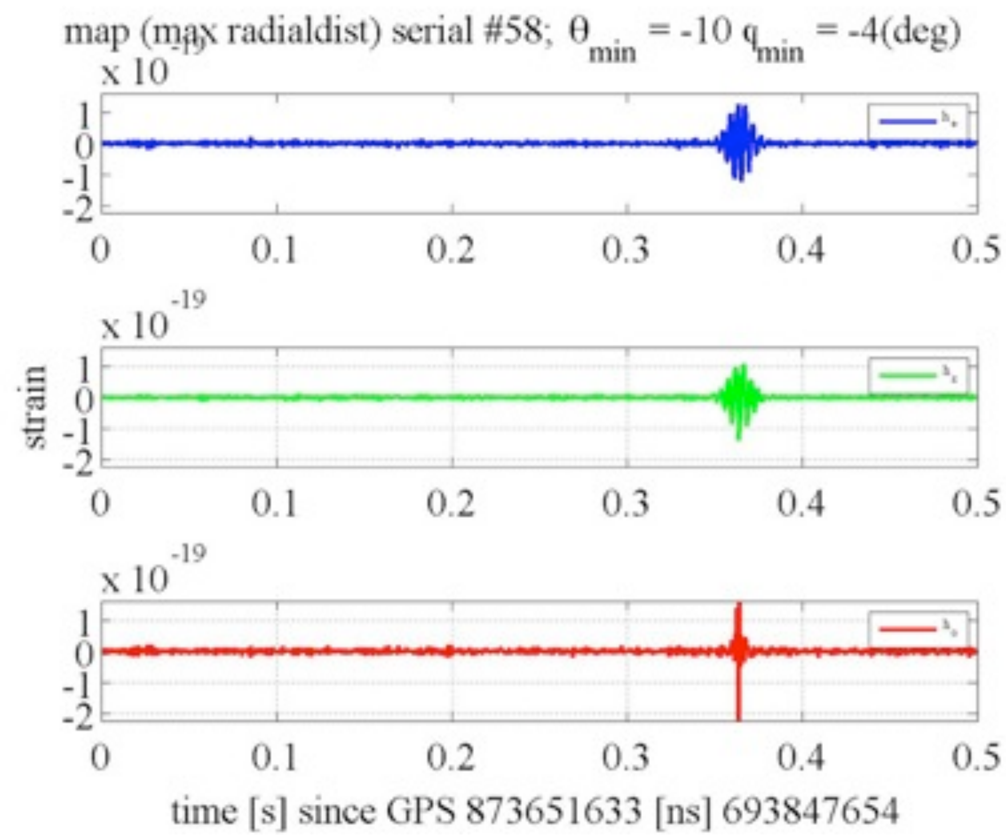
- **As to injection signal, to see $h_\circ$ clearly, I used spike-like burst as $h_\circ$.**
- **Although the grid of lat-lon map is coarse (4°x4°) in the simulation, ho is reconstructed clearly.**



h_+, $h_\times$: SG235Q9
$h_\circ$: Not injected

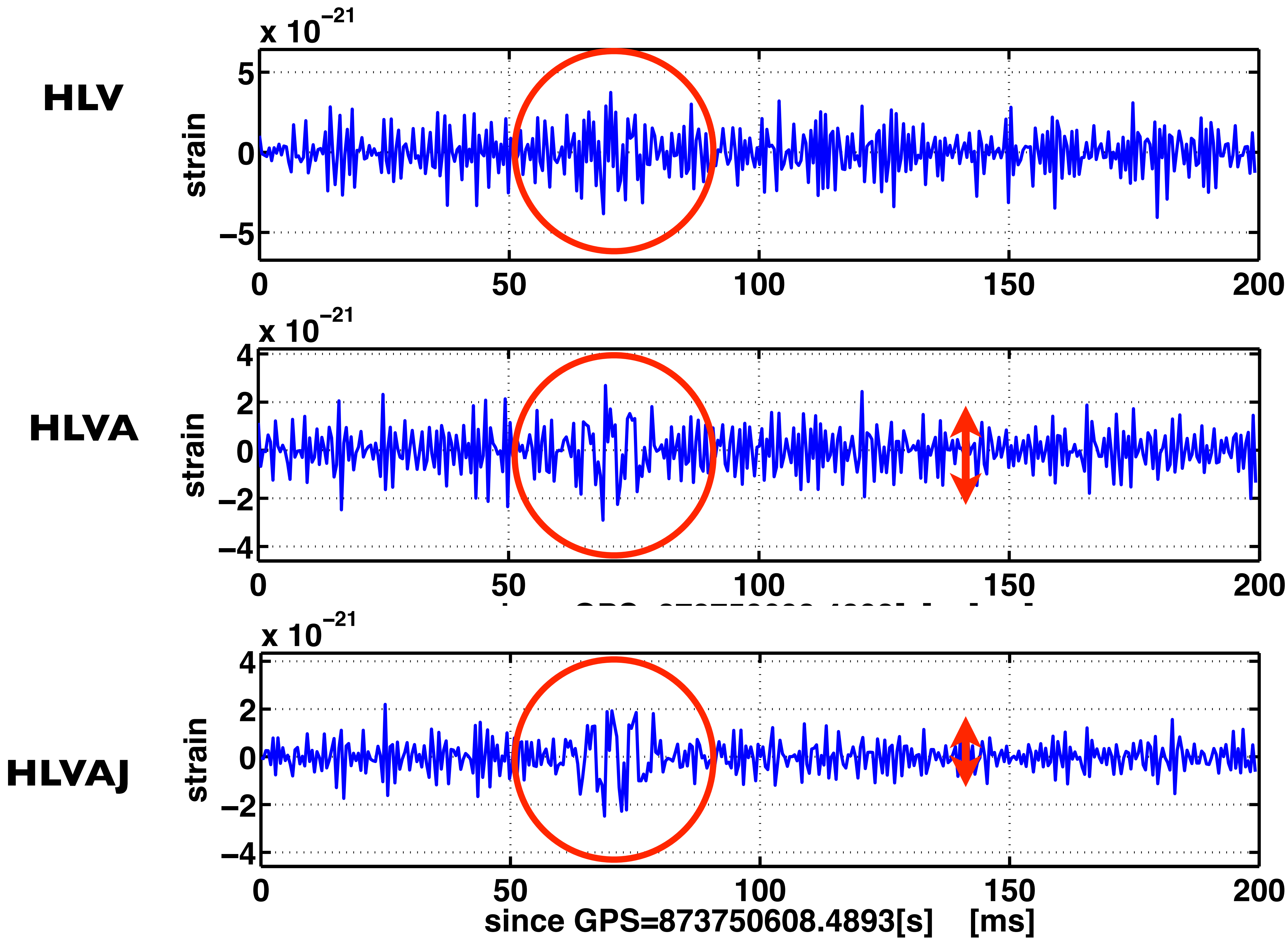


h_+, $h_\times$: SG235Q9
$h_\circ$: Spike-like burst



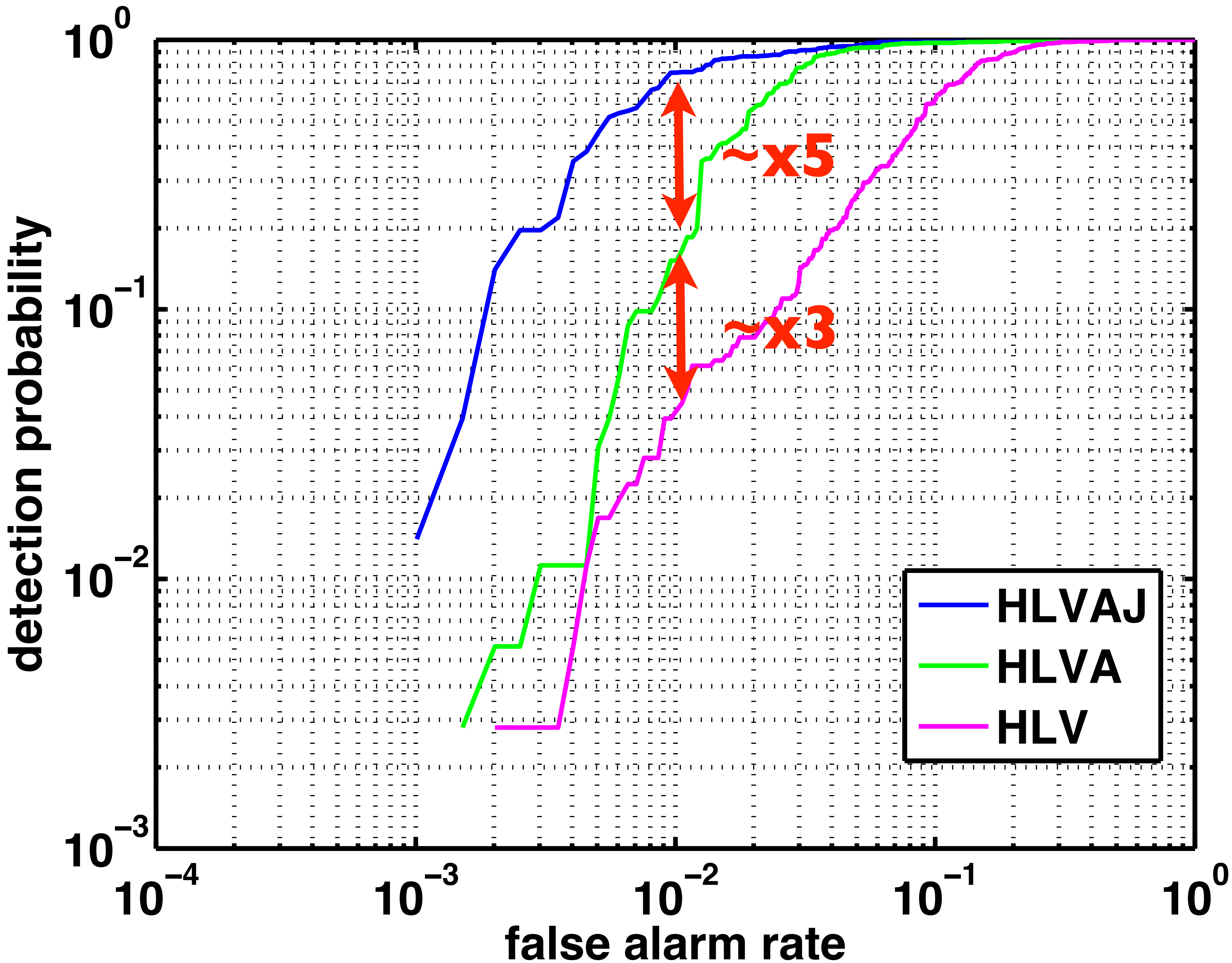
Reconstructed scalar GW

- **Astrophysical model used is a spherically symmetric core collapse with 10Mo at the distance of 10kpc from the earth.(M.Sibata,1994)**



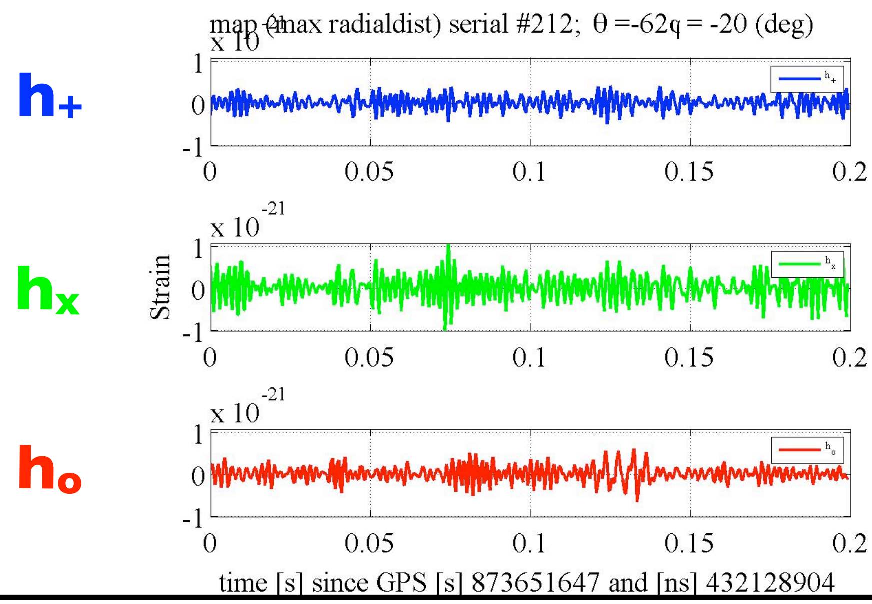
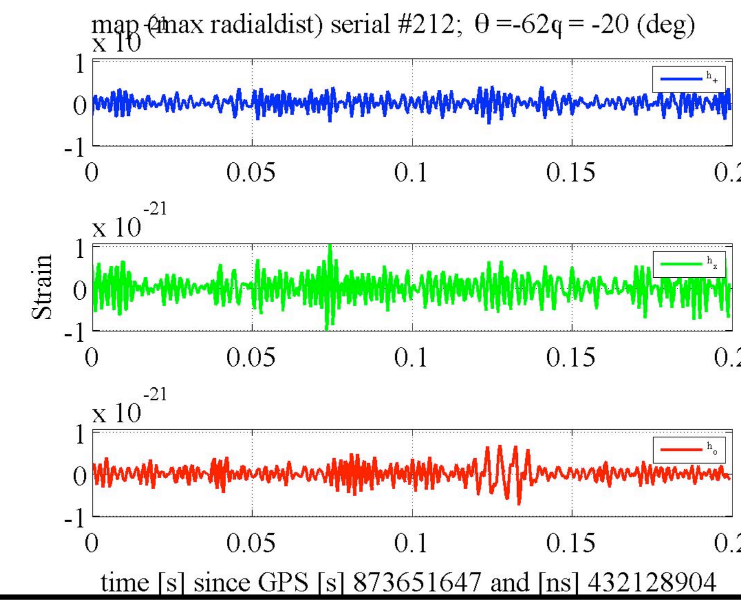
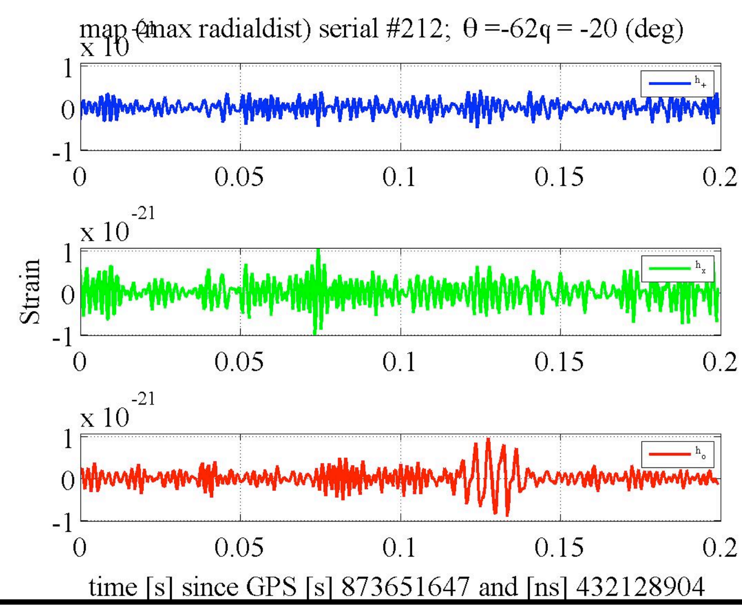
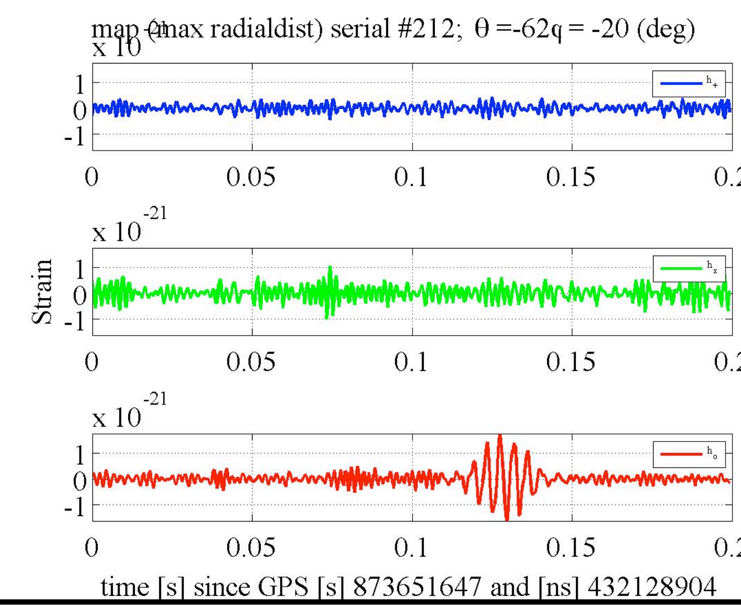
ROC curve for adv. networks

- **Simulated GWs is from spherical core collapse at 10kpc. Sky directions are uniformly distributed.**

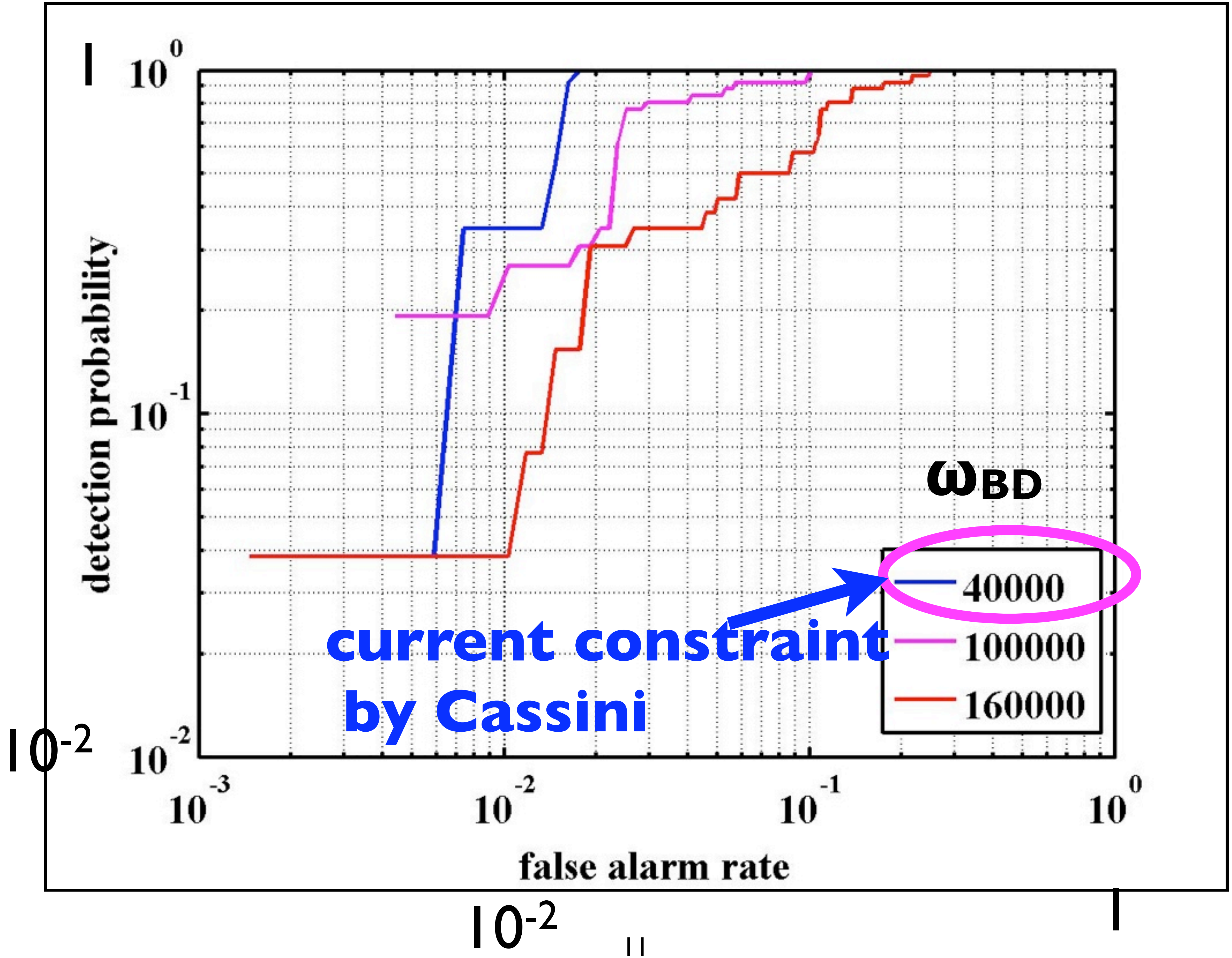


Waveform reconstructions for ω_{BDs}

We performed simulations to reconstruct scalar gravitational waves with ω_{BD} = 40000,80000,120000,160000.
This simulation uses the design sensitivity of advLIGO for LIGO, VIRGO, and LCGT.
Astrophysical model used is the same as the previous simulation.

ω_{BD}=160000	ω_{BD}=120000
	
ω_{BD}=80000	ω_{BD}=40000
	

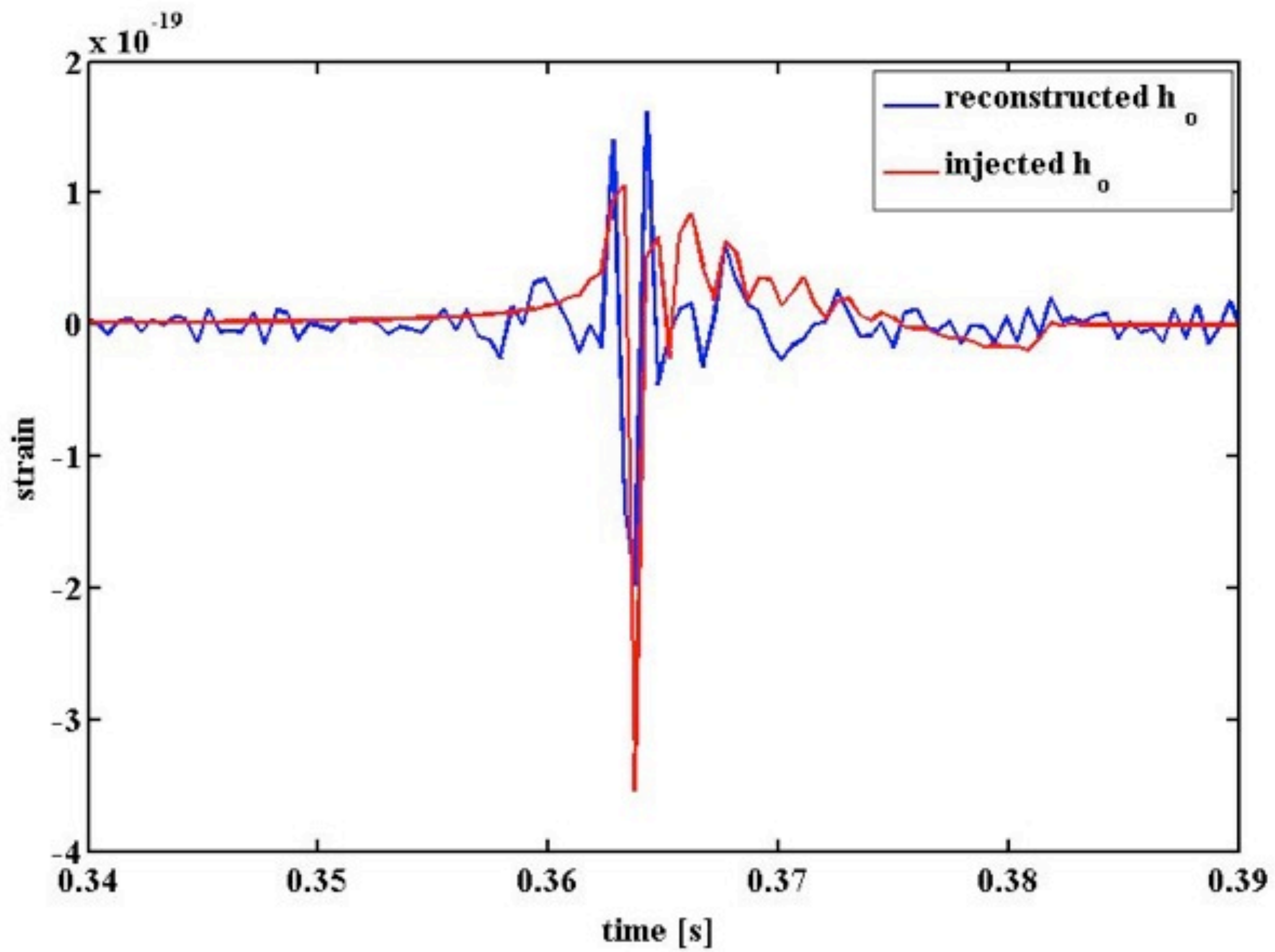
ROC curve for ω_{BD}



Summary

- We discuss search for scalar GW from Galactic spherical core collapse in Brans-Dicke theory with various adv det. network.
- Although depending sky location and models, it is possible to put stronger constraint on ω_{BD}.
- LCGT and LIGO-Australia play an important role for search for scalar gravitational waves
- We need numerical simulations of scalar GW in S-T theory.

Wavrform comparison



Red plot is injected ho signal and blue plot is the reconstructed ho.
The difference at the low frequency region comes from the data conditioning step.
Detector noise at low frequency is very high, such region is cut at the step.