Impact of the Global Correlated Magnetic Noise on Phase Transition SGWB Searches

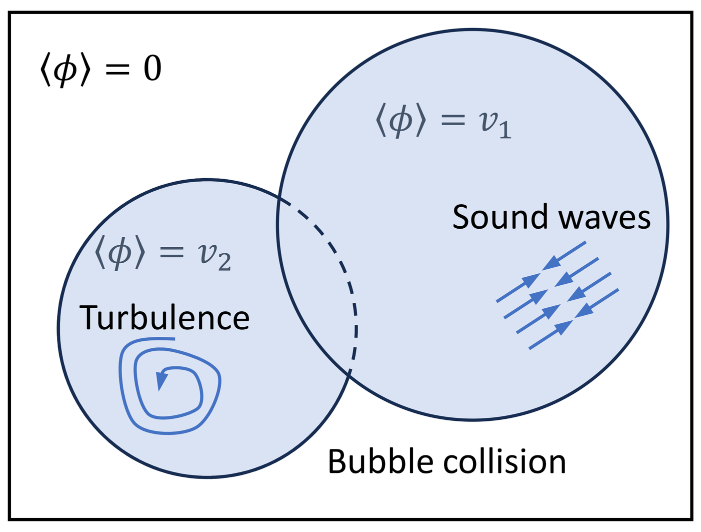
Tatsuki Washimi (NAOJ)

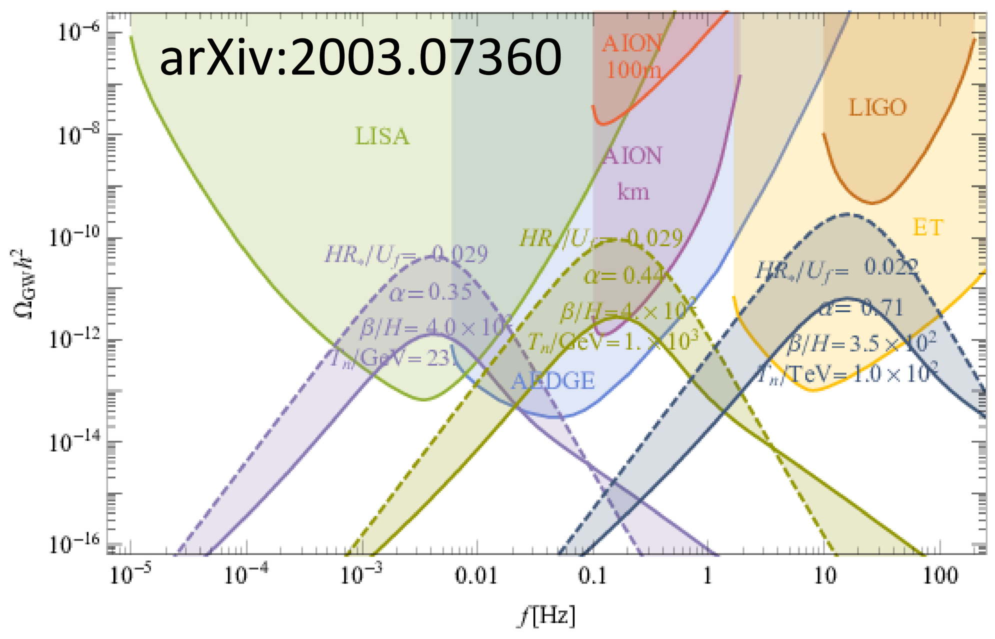
科研費 KAKENHI 22K14062

A stochastic gravitational wave background (SGWB) is a weak and persistent background of gravitational waves (GWs) and can provide valuable insights into the origins and evolution of the universe. To detect the SWGB with ground-based interferometric detectors, cross-correlations between multiple GW detectors are calculated and local noise is canceled; however, global coherent noises, such as the Schumann resonance, remain and affect the observation. We evaluate its effect on phase transition SGWB searches based on the Fisher matrix formalism.

Phase Transition SGWB

Phase transition of vacuum in the early universe is one candidate of an SGWB source, which has a peak in its frequency spectrum. ($\mathcal{O}$(100TeV) ⇒ peak at $\mathcal{O}$(10Hz))





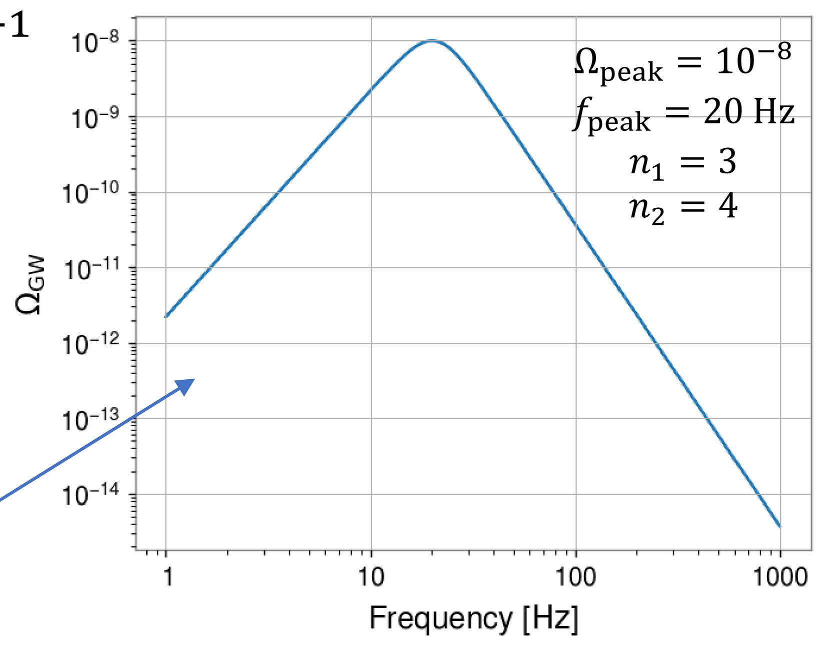
The energy density can be proximally written as a broken-power-low model with two index parameters. Sound wave case has the sharpest spectrum.

Broken-power-low

$$\Omega_{\rm GW}(f) = \Omega_0 \times \left[\left(\frac{f}{f_0}\right)^{-n_1} + \left(\frac{f}{f_0}\right)^{n_2}\right]^{-1}$$

Source	n_1	n_2
Bubble collision	2.8	2
Turbulence	3	5/3
Sound waves	3	4

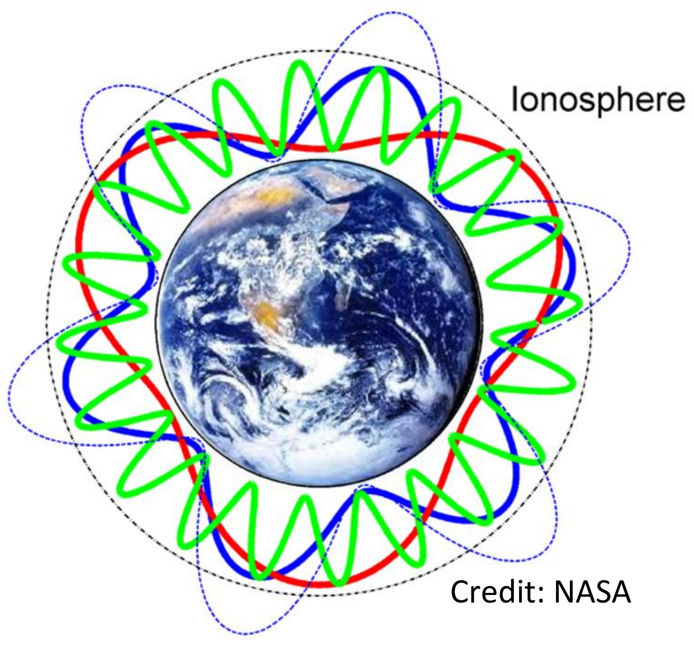
Sachiko Kuroyanagi *et al*, JCAP11(2018)038



Global Correlated Magnetic Noise

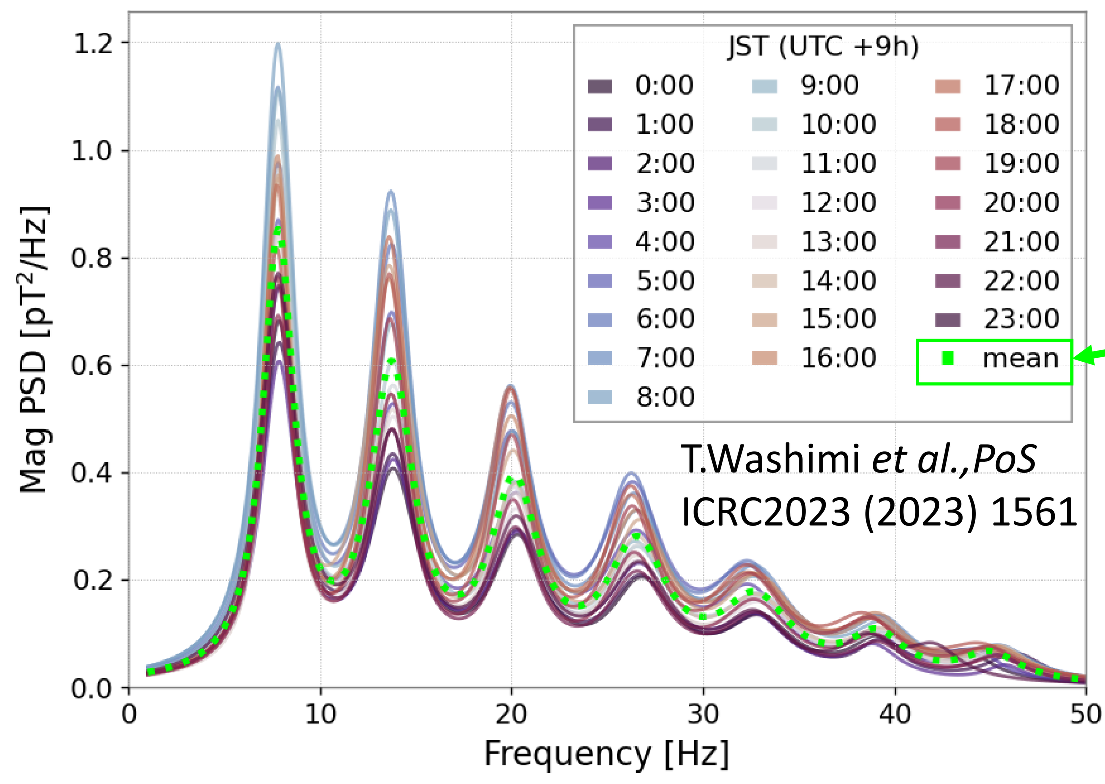
The Schumann resonance is a natural phenomenon in which the Earth's electro-magnetic field resonates between the ionosphere and the Earth's surface. Schumann resonances generate correlated noise through instrumental magnetic couplings to GW detectors.

We are monitoring the magnetic field of the Schumann resonance at the entrance of the KAGRA and use it in this study.



Power spectral density of the Schumann resonance

$$M(f) = \sum_{\ell=1}^{6} \frac{A_\ell \cdot (f_\ell/2Q_\ell)^2}{(f-f_\ell)^2 + (f_\ell/2Q_\ell)^2}$$



We use this in this study.

T.Washimi *et al.,PoS* ICRC2023 (2023) 1561

Fisher analysis

To detect an SGWB using ground-based interferometric GW detectors (LIGO, Virgo, KAGRA, and other detectors), the cross-correlation between multiple GW detectors is calculated and local noise is canceled.

i-th detector's signal: $s_i(t) = \underbrace{h_i(t)}_{\text{GW signal}} + \underbrace{n_i(t)}_{\text{Noise}}$

cross-correlation: $U_{ij} = \langle s_i s_j \rangle = \langle h_i h_j \rangle + \cancel{\langle h_i n_j \rangle} + \cancel{\langle n_i h_j \rangle} + \underbrace{\langle n_i n_j \rangle}_{\text{Correlated noise}}$

In this study,

$$U_{ij}^{\rm GW}(f) = \langle h_i h_j \rangle = \frac{3H_0^2}{10\pi^2}\frac{\Omega_{\rm GW}(f)}{f^3}\gamma_{ij}(f)$$

$$U_{ij}^{\rm Mag}(f) = \langle n_i n_j \rangle = r_i(f)\cdot r_i(f)\sum_{\ell=1}^{6} M_\ell(f)\cdot \gamma_{ij,\ell}^{\rm Mag}$$

By the Fisher analysis method, we can estimate

① Statistical errors σ_a with considering the correlated noises

② Biases $\Delta\theta_a$ with missing the correlated noises

$$\sigma_a = \sqrt{(F^{-1})_{aa}}, \qquad \Delta\theta_a = \sum_b [\mathcal{F}^{-1}]_{ab}\, s_b,$$

where

$$F_{ab} = 2T_{\rm obs}\sum_{(i,j)}\int_{f_{min}}^{f_{max}} \frac{\partial_a U_{ij}\partial_b U_{ij}}{S_i S_j}df,$$

$$\mathcal{F}_{ab} = 2T_{\rm obs}\sum_{(i,j)}\int_{f_{min}}^{f_{max}} \frac{\partial_a U_{ij}^{\rm GW}\partial_b U_{ij}^{\rm GW} - U_{ij}^{\rm Mag}\partial_a\partial_b U_{ij}^{\rm GW}}{S_i S_j}df,$$

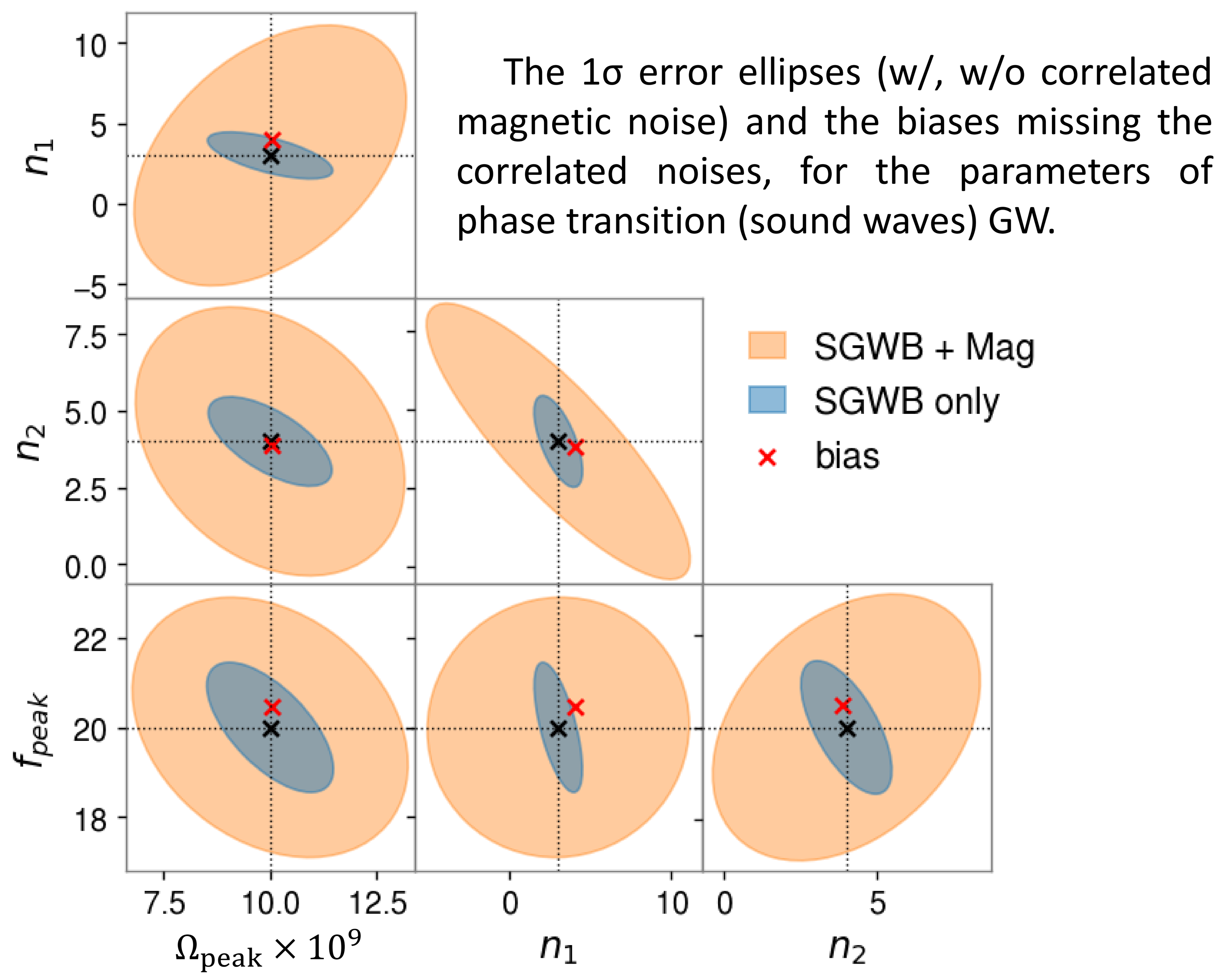
$$s_b = 2T_{\rm obs}\sum_{(i,j)}\int_{f_{min}}^{f_{max}} \frac{U_{ij}^{\rm Mag}\partial_b U_{ij}^{\rm GW}}{S_i S_j}df$$

$S_i(f)$: Sensitivity (PSD) of the i-th GW detector (HLVK),

T_{obs} : Observation time

In *Himemoto et al., PRD* **107**, 064055 (2023), a study for astronomical sources was performed. In that case, the effect of the correlated magnetic noise was not so serious. Our work is based on this paper.

Result (4-detectors of HLVK, 1-year observation)



The 1σ error ellipses (w/, w/o correlated magnetic noise) and the biases missing the correlated noises, for the parameters of phase transition (sound waves) GW.

In this study, we investigated the impact of the global correlated magnetic noise of the Schumann resonance on searching for SGWB caused by phase transition (sound waves) based on the Fisher analysis formalism. As a result, we found that the error ellipses for the estimated GW parameters become significantly larger and signs of some error correlation are changed due to the existence of magnetic noise. Some biases by missing the magnetic noise are plotted outside of the error ellipses for the magnetic noise-free case. That is quite an interesting result compared to the previous work for astronomical-originated SGWB. We are planning to perform systematic surveys for many values of GW parameters.