Magnon gravitational wave detector

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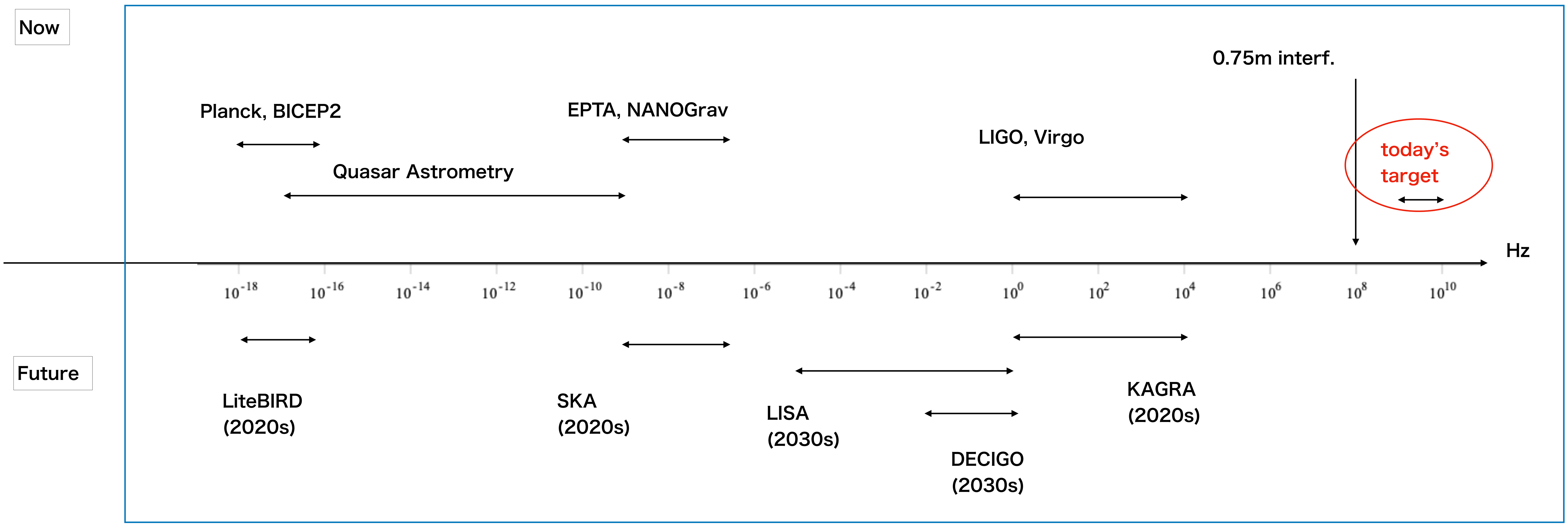
Refs:
- AI, T. Ikeda, K. Miuchi, J. Soda, Eur. Phys. J. C 80 (2020) 3, 179
- AI, J.Soda, Eur. Phys. J. C 80 (2020) 6, 545
- AI, J.Soda, arXiv: 2212.04094 (2022)[gr-qc]



Multi-frequency GW observations have started. In particular, high frequency range around GHz should be studied intensively → Why GHz?

Many sources of high-frequency gravitational waves around GHz: theoretically

- Corresponding to the energy scale of inflation (Cut off of the primordial GW, Reheating)
- Light primordial black hole $f \sim 10^3 \times \left(\frac{M_\odot}{m_1 + m_2}\right) \mathrm{Hz}$
- Superradiance from bosonic fields like
- Gravitational waves from thermal scatterings (A. Ringwald, et al. (2021), P. Gubler, et al. (2022))
- GWs from extra dimensions (brane-world BHs) (S.S.Seahra et.al, PRL 94, 12302 (2005))
- Unknown sources

→ In order to detect the above high-frequency GW sources, we need a new idea

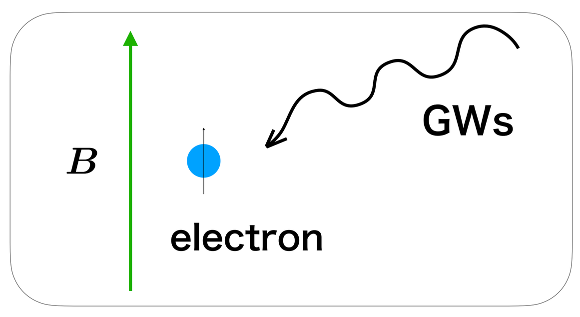
We would like to seek a method to observe GWs around GHz.

$$\mathrm{GHz} \sim \mu\mathrm{eV} \sim \mathrm{cm}$$

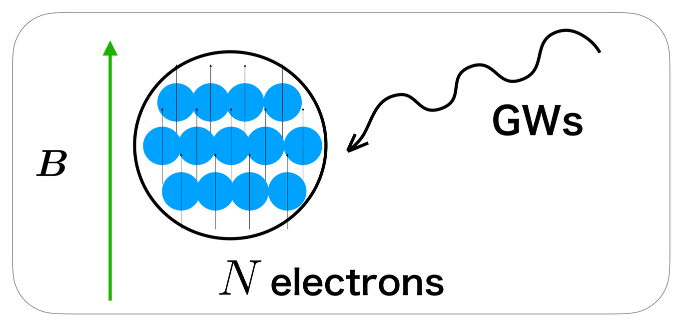
This scale is just corresponding to tabletop size experiments in condensed matter physics, quantum optics, quantum information, etc.

→ We will show that magnons (collective spin excitation) can be utilized for GW detection around GHz.

Due to the interaction, GWs can induce spin resonance of an electron.



We now further consider a collective spin system (magnon)



→ Then, the resonance strength is enhanced by $\sqrt{N} \sim \sqrt{10^{20}} \sim 10^{10}$

We consider the Dirac equation in curved spacetime

$$i\gamma^{\hat{\alpha}} e^{\mu}_{\hat{\alpha}} \left(\partial_\mu + \Gamma_\mu + ieA_\mu\right)\psi = m\psi$$ with a metric: $$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$

↓ Taking the non-relativistic limit and get a Hamiltonian for the Schrodinger equation

$$\mathcal{H}_{spin} \simeq -\mu_B (2\delta_{ij} + h_{ij}) \hat{S}^i B^j$$

magnetic moment

Interaction between a spin and GWs in the presence of an external magnetic field

($\mu_B = \frac{|e|}{2m}$: Bohr magneton, $\hat{S}^i$: spin, B^j : external magnetic field.)

※ More precisely, we need to use a fermi normal coordinate in order to take into account the equivalence principle properly

(AI, J.Soda, Eur. Phys. J. C 80 (2020) 6, 545)

Constraints & Sensitivity