GW Missions using Ranging-with-Timing and ZAIGA-CE GW-Detection Prototype

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Two-way ranging in the solar-system using radio waves and atomic (molecular) clocks has been implemented for more than fifty years. When gravitational waves come to the solar-system, this method would measure the distance change due to GWs if the precision is high enough. In fact, Doppler tracking of spacecraft can be considered as the first space GW experiment. With technological development, one-way and two way interplanetary laser ranging were proposed and demonstrated [1]. Lunar laser ranging is routinely performed. T2L2 have also been implemented. With the recent demonstration of systematic uncertainty of optical clock to below 10^{-18} [2], and of measurement instability of optical clock to 3.2×10^{-19} [3], development to 10^{-20}-level could be envisaged. A clock GW mission with laser link would then be a good possibility after the 3G ground-based GW detectors and first-generation space borne laser-interferometric GW detectors, especially with AU or larger arm length. To anticipate such a development, we propose to use the ZAIGA facility [4] to develop a ZAIGA-CE (CE: Clock Experiment) GW-Detection Prototype consists of 2 optical clocks at the end of 1 km arm length tunnel (plan to start excavation in June) using a laser link between them. Various space options and the preliminary scheme of ZAIGA-CE will be presented in this meeting.

[1] For a review, see, W. T. Ni, GW detection in space, Int. J. Mod Phys. D **25**, 1630001 (2016); Chapter 12 *One Hundred Years of General Relativity: From Genesis and Empirical Foundations to Gravitational Waves, Cosmology and Quantum Gravity*, ed. W.-T. Ni (World Scientific, Singapore, 2017, open access, https://www.worldscientific.com/doi/10.1142/9389-vol1) .
[2] S. M. Brewer, J.-S. Chen, A. M. Hankin, E. R. Clements, C. W. Chou, D. J. Wineland, D. B. Hume, D. R. Leibrandt, An $^{27}Al^{+}$ quantum-logic clock with systematic uncertainty below 10^{-18}, arXiv:1902.07694.
[3] W. F. McGrew, X. Zhang, R. J. Fasano, S. A. Schäffer, K. Beloy, D. Nicolodi, R. C. Brown, N. Hinkley, G. Milani, M. Schioppo, T. H. Yoon, and A. D. Ludlow, Atomic clock performance enabling geodesy below the centimetre level, Nature, **564**, 87 (6 December, 2018).
[4] ZAIGA Collaboration, Zhaoshan long-baseline Atom Interferometer Gravitation Antenna, in preparation.