Axion dark matter search with gravitational wave detectors: ADAM-GD

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Reference

1. KN+, Phys. Rev. Lett. 123, 111301 (2019)

2. KN+, Phys. Rev. D 104, 062008 (2021)

Dark matter search

- Although weakly interacting massive particles (WIMP) is earnestly searched as an attractive dark matter candidate so far, there is no sign of its detection.
- These days, wide searches with new schemes are required. → Wide mass range with new methodologies.



Workshop on Very Light Dark Matter 2021 (Remote, Sep. 27th, 2021)

Axion and axion-like particle (ALP)

- Axion was originally proposed in 1970s to solve the strong CP problem in QCD physics.
- Recently, string theory suggested a plentitude of ALPs.
- Feature (In this talk, ALPs are also called axions.)
 - -Typically have a small mass (<< eV).
 - -Weakly couple with gauge bosons. In particular photon.
 - E.g.: Primakoff effect (axion-photon conversion).



Schematic of the Primakoff effect.

Axion dark matter search

- The conventional way to probe axion is to use strong magnets, i.e. the Primakoff effect.
 - However, the magnet could cause noises (vibration/electric noise) and increase cost.
- Recently, new approaches to search for axion were proposed that do not need any magnets but use interferometer.



Conventional way with the Primakoff effect. (J. K. Vogel+, arXiv1302:3273)



Axion interaction with photons

 Axion varies phase velocity between two circular-polarized photons.

 $c_{
m L/R} = \sqrt{1\pm \frac{g_{a\gamma}a_0m_a}{k}}\sin(m_at+\delta_{ au})$ Axion-photon coupling

 (This will be measured) Axion field amplitude Photon wave number
 This leads to the polarization modulation of the linearly polarized light.

Axion mass



Polarization modulation caused by axion-photon coupling.

How to search for axions with interferometer

(Case1) Axion is very light [= Polarization modulation is very slow]



How to search for axions with interferometer

(Case2) Axion is relatively heavy [= Polarization modulation is relativity fast]



KAGRA



Axion dark matter search with gravitational wave detectors (ADAM-GD)



- This scheme can be applied to GW detectors just by putting polarizer and photodetectors.
- Axion dark matter search can be performed even during the GW observation.

Sensitivity estimation



Sensitivity estimation



Polarization monitor at TMS in KAGRA

- Polarization monitor has been mostly installed at X-arm transmission monitor system (TMS).
 - This is used for polarization
 monitor during commissioning.

X-arm

ICRR

-arm



Picture of TMS at X-end. [klog #17692]

Summary

- Axion is an astronomically well-motivated candidate for dark matter.
- Axion makes phase velocity modulation (or polarization-modulation) of the light.
- New scheme to search for the axion dark matter with GW detectors (ADAM-GD) with a few additional optics.

1. KN+, Phys. Rev. Lett. 123, 111301 (2019)

- 2. KN+, Phys. Rev. D 104, 062008 (2021)
- KAGRA can improve the current limit achieved by CAST.
- Polarization monitor that can be used for axion search has been installed in KAGRA.



Dark matter search with interferometer

- <u>Axion-like particles (Pseudoscalar)</u>
 - -A. Melissinos, PRL 102, 202001 (2009)
 - -W. DeRocco+, PRD 98, 035021 (2018)
 - -I. Obata+, PRL 121, 161301 (2018)
 - -H. Liu+, PRD 100, 023548 (2019)
 - -KN+, PRL 123, 111301 (2019)
 - -D. Martynov+, PRD 101, 095034 (2020)
 - -KN+, PRD 104, 062008 (2021)

• Scalar dark matter

- -Y. Stadnik+, PRL 114, 161301 (2015)
- -Y. Stadnik+, PRA 93, 063630 (2016)
- -A. Geraci+, PRL 123, 031304 (2019)
- -H. Grote+, PRR 1, 033187 (2019)
- -S. Morisaki+, PRD 100, 123512 (2019)
- -C. Kennedy+, PRL 125, 201302 (2020)

- <u>U(1)B or U(1)B-L gauge bosons</u> (vector)
 - P. Graham+, PRD 93, 075029 (2016)
 - -A. Pierce+, PRL 121, 061102 (2018)
 - -H-K Guo+, Commun. Phys 2, 155 (2019)
 - -Y. Michimura+, PRD 102, 102001 (2020)
 - -D. Carmey+, New J. Phys. 23 023041 (2021)
 - -J. Manley+, PRL 126, 061301 (2021)
 - -LVK Collab., arXiv:2105.13085 (2021)
- Other candidate (not ULDM)
 - –A. Kawasaki, PRD 99, 023005 (2019) [kgscale DM]
 - –S. Tsuchida+, PRD 101, 023005 (2020)[WIMP]
 - –F. Monteiro+, PRL 125, 181102 (2020)[Composite dark matter]

Not exhaustive.

The ones that require magnetic field are not listed.

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Bonus slide Basic idea how to prove polarization rotation

