



D03 Quantum Gravity Constraints on Dark Matters

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Goal: curve out the huge parameter space of dark matter models

using **consistency conditions of quantum gravity!**

cf. C01 group of Yamazaki-san, my talk in the C01 session

Motivation

Experimental **upper bounds** on SM-DM interactions have been improving a lot!

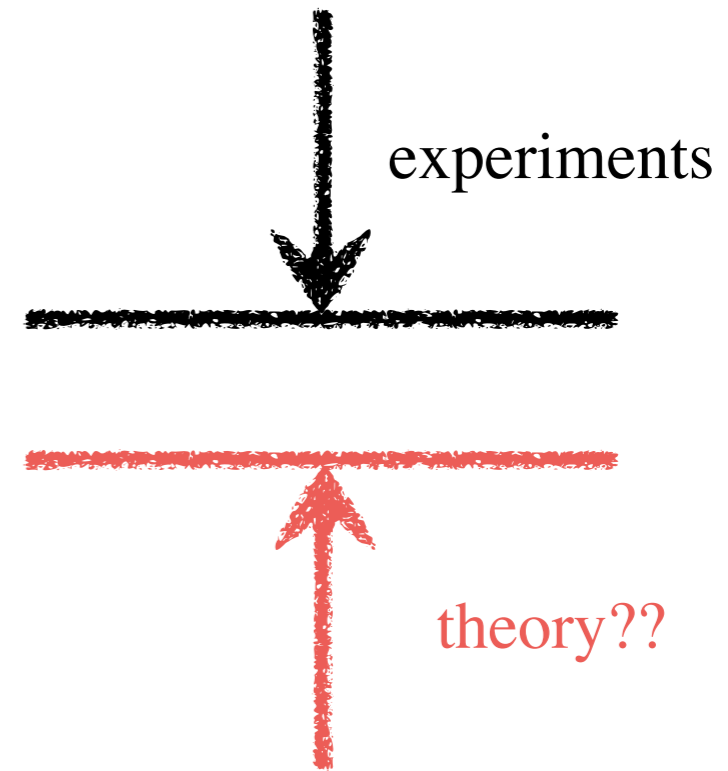
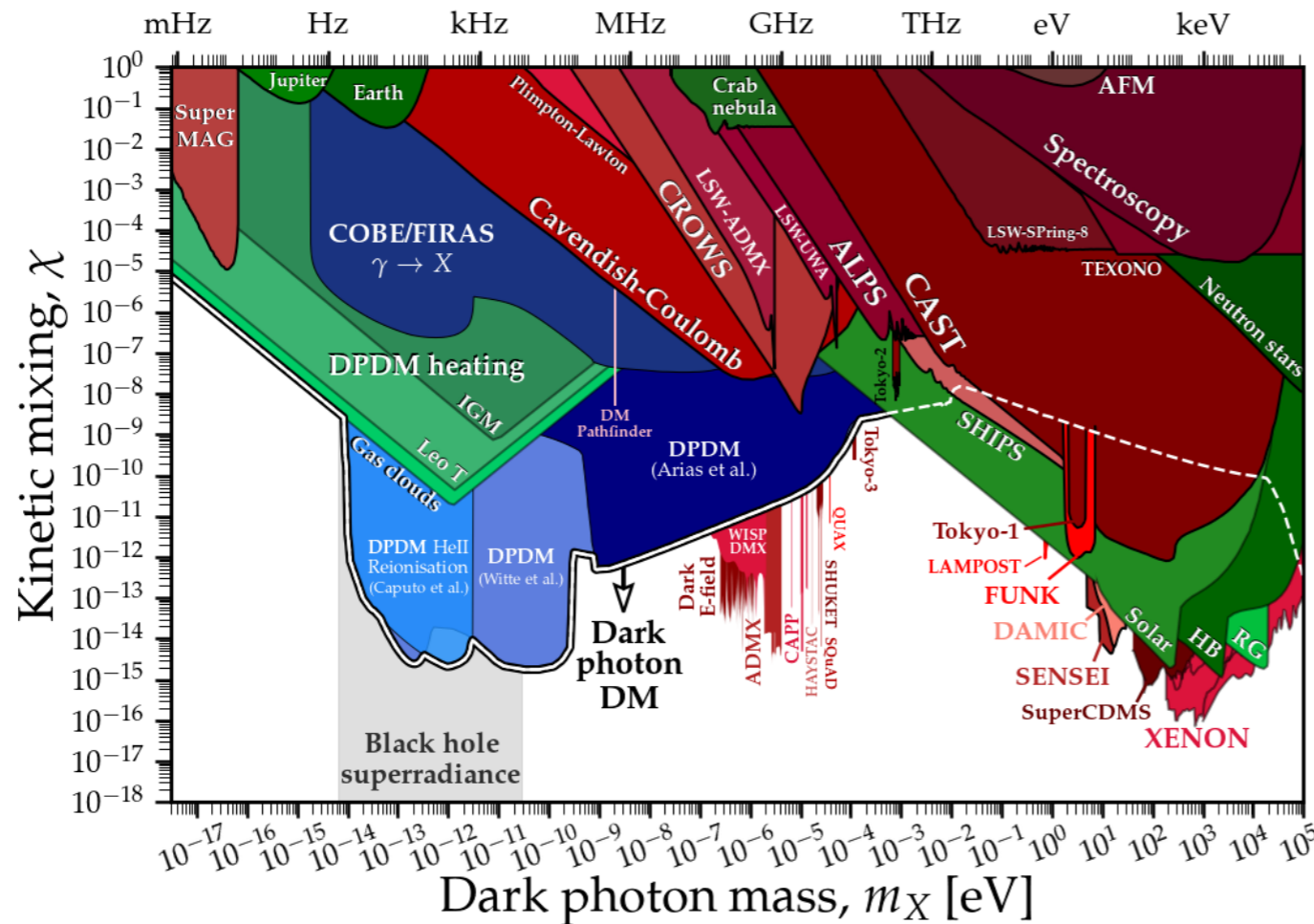


Fig: dark photon search as an example

Theoretical **lower bounds** would be useful as a target sensitivity of experiments.

※ experiments + theories → close the window from both sides!

Progress in the Swampland Program

In the Swampland Program [Vafa '05],

QG constraints on symmetries & interactions have been proposed/studied.

ex. Weak Gravity Conjecture (WGC) [Arkani-Hamed et al '06]

In 4D graviton-photon system, there should exist a charged state with

$$g^2 q^2 \geq \frac{m^2}{2M_{\text{Pl}}^2} \text{ (Coulomb force } > \text{ gravity).}$$

Its magnetic version states that $gM_{\text{Pl}} \gtrsim \Lambda$ (Λ : UV cutoff).

※ quantitative generalization of the claim “no global symmetry in QG.”

[Banks-Dixon '88, Banks-Seiberg '10, Harlow-Ooguri '18, ...]

※ **A lower bound on gauge coupling!**

There are many attempts toward a proof of WGC and its generalization.

[See Harlow et al '22 for a review]

A lower bound on SM-DM interactions along this line of consideration?

Achievements in FY2021

In [Aoki-Loc-TN-Tokuda PRL 127, 091602],

we studied **unitarity of gravitational scattering** in the **Standard Model** coupled to GR, generalizing earlier works toward a derivation of WGC and its generalization.

[Cheung-Remmen '14, Andriolo-Junghans-TN-Shiu '18, Alberte et al '20]

Under certain technical assumptions,

1. we identified the cutoff scale of gravitational Standard Model as $\Lambda \sim 10^{16}$ GeV, which is reminiscent of **grand unification**,

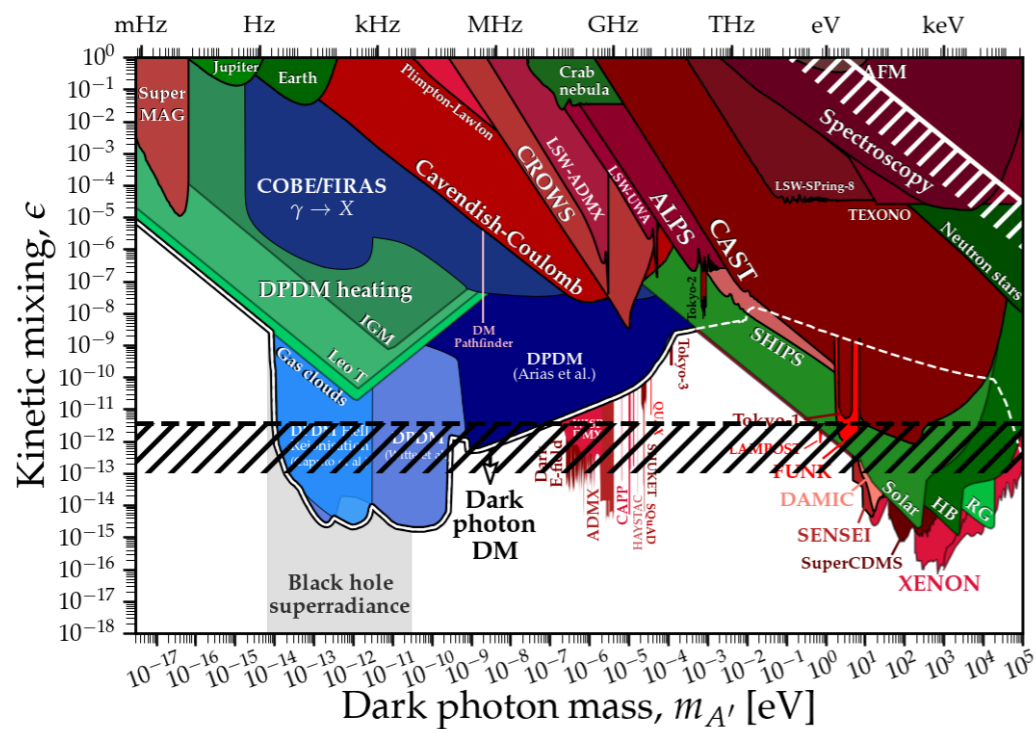
2. we derived a **WGC-like bound on the electron Yukawa coupling** $\Lambda < \sqrt{\frac{1440}{11}} y_e \sin \theta_W M_{\text{Pl}}$.

- Our work is the first application of recent developments on gravitational S-matrix bootstrap (in particular, positivity bounds in gravity) to our real world.
- Also, our results suggest that the S-matrix bootstrap is useful in deriving QG constraints on models of particle physics and cosmology.

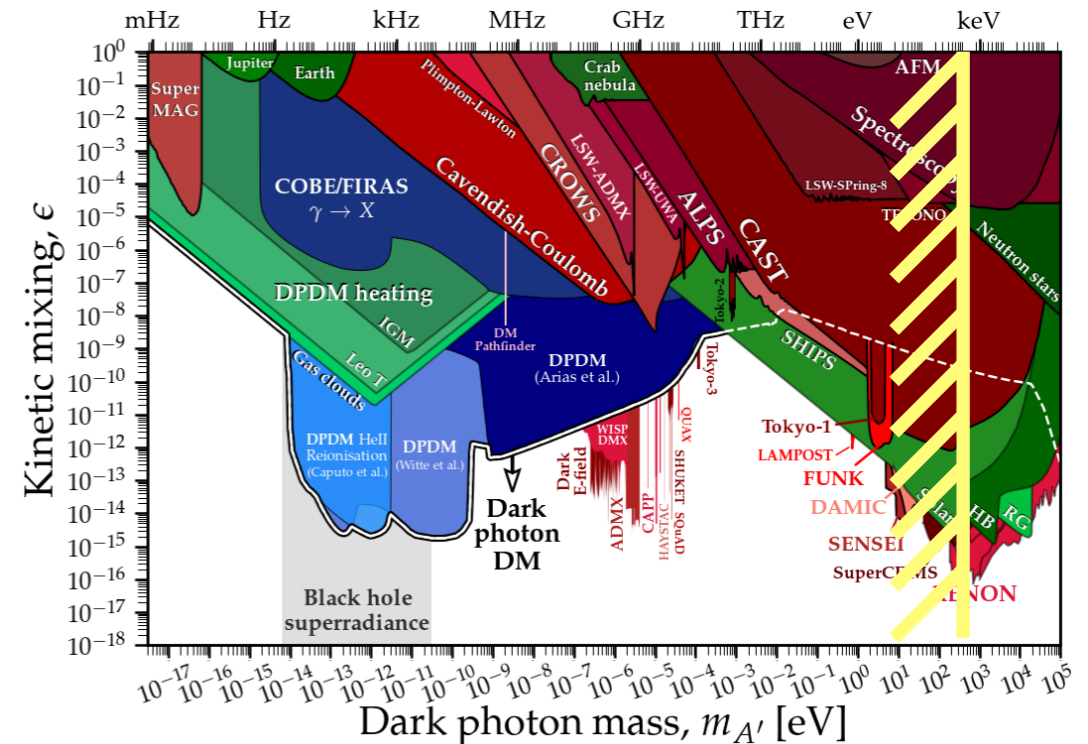
Achievements in FY2022

In [TN-Sato-Tokuda '22],

we generalized the analysis to **dark photon** models as an example for dark sector models.



dark photon model A



dark photon model B

Under the same assumptions made in the SM analysis, we showed that unitarity of gravitational scattering can be useful to **curved out the DM theory space from a complementary direction**. See my talk at the C01 session of tomorrow for details.

Prospects for FY2023-2024

After presenting our work at the DM symposium of the last year etc,
we started collaboration with the C01 group!

With my collaborators (Aoki, Sato, Tokuda) and the C01 members (Saito, Shirai, Yamazaki),
we are working on

- 1) comprehensive unitarity analysis of DM models coupled to gravity
- 2) theoretical studies on gravitational S-matrix bootstrap

See also the talk by Katsuki Aoki in the C01 session tomorrow.

My proposal for the FY2023-2024 公募研究 along this line has been approved!

I hope to make progress with the C01 group and interact more also with other groups!