Light Dark Matter: Motivations and Experimental Searches

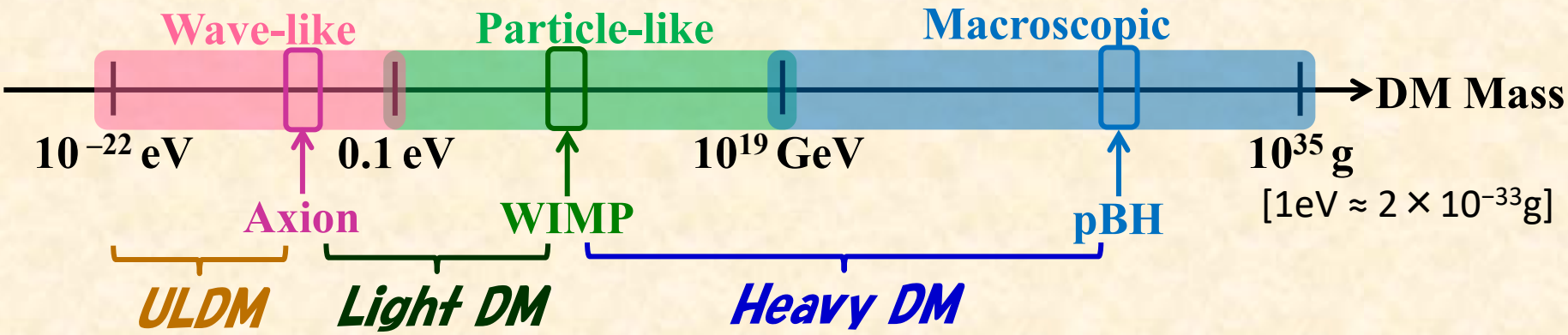
Shigeki Matsumoto (Kavli IPMU)

Contents:

- ✓ Dark matter problem and popular candidates
- ✓ WIMPs: well-studied particle DM candidates.
- ✓ Light DM: alternative particle DM candidates.
  - Motivations and concrete candidates
  - Indirect detection of light DM
- ✓ Summary

DM problem & DM candidates

We know dark matter (DM) exists, but little about its nature:



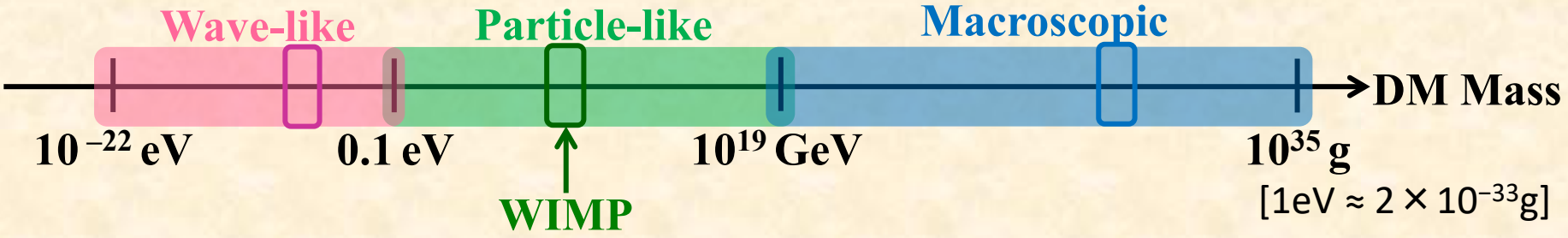
Popular candidates that have been widely discussed:

- ✓ **Axion**, motivated by the strong CP problem in the SM.
- ✓ **WIMP**, motivated by the electroweak hierarchy problem.
- ✓ **pBH**, described within the framework of Einstein gravity.

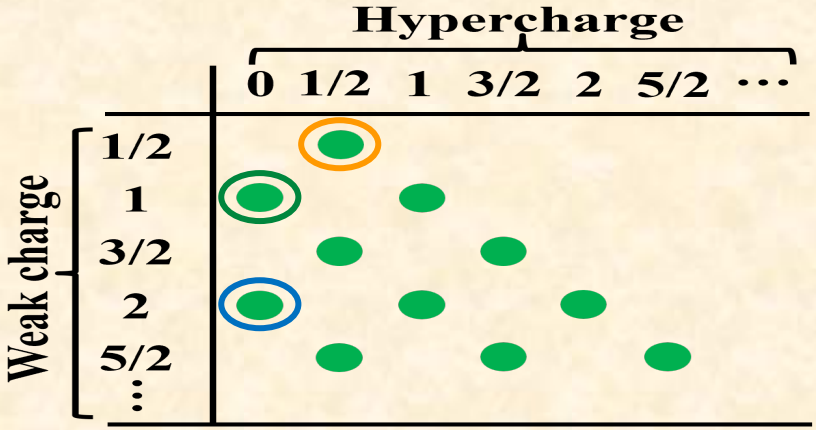
DM candidates in the ultralight and heavy mass regimes:

- ✓ **ALPs, Ultralight scalars (moduli, dilatons), Fuzzy DM**
  The first two naturally arise from string compactification, while the last exhibits wave effects on galactic scales.
- ✓ **Few candidates, such as composite DM, Q-balls, solitons.**
  From hidden strong dynamics or stable field configurations.

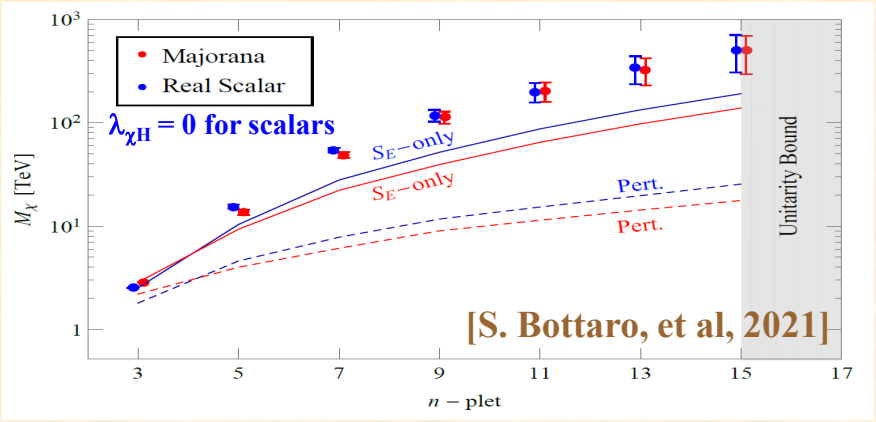
Uncharged WIMP



O Electroweak-charged candidates remain to be fully explored:



- ✓ Inert Higgs DM in 2HDM
  Higgsino DM in SUSY (FPS)
- ✓ Wino DM in SUSY (AMSB)
  1st KK weak boson in UED
- ✓ Minimal dark matter.



Predicted in various BSM models.
Masses are typical O(1-10) TeV.

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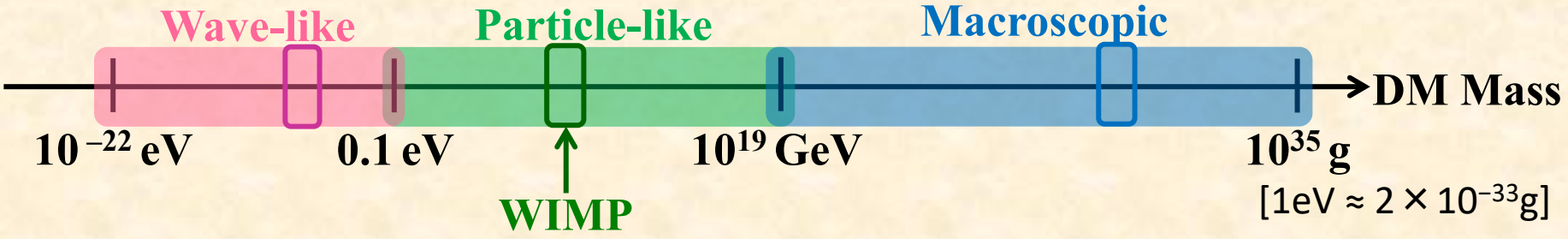

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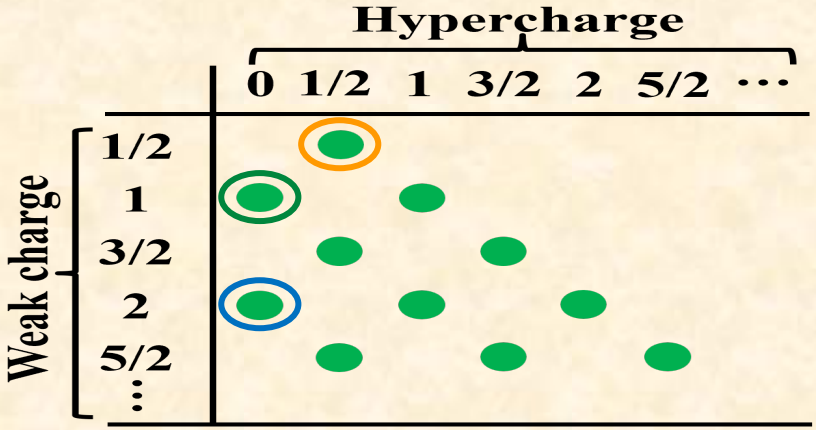

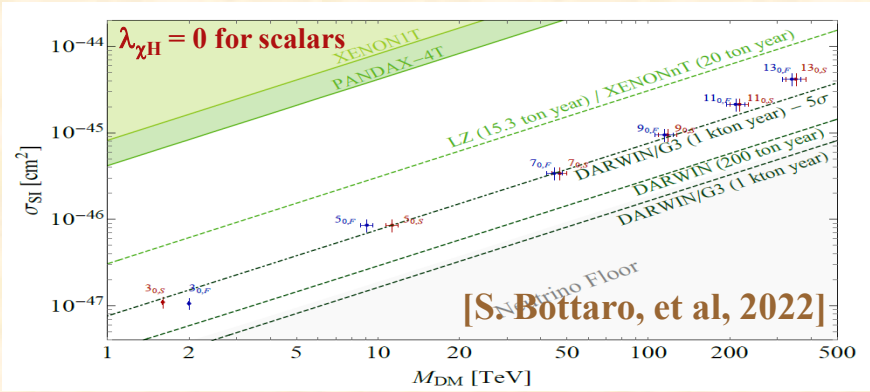

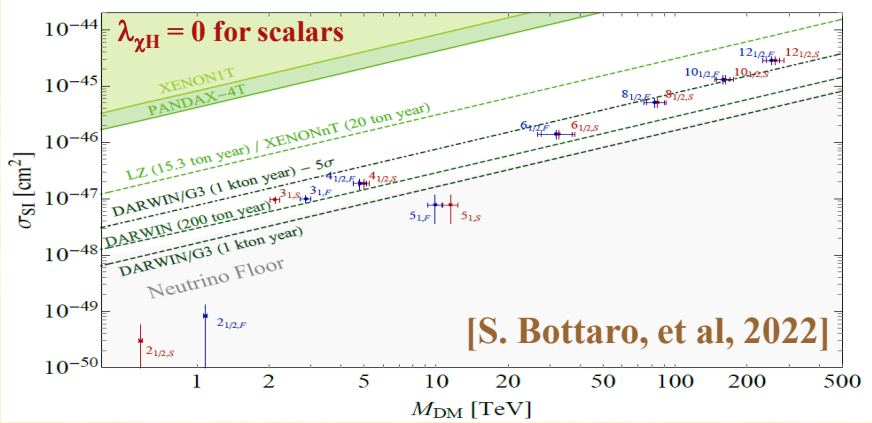

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[Hisano, Ishiwata, Nagata, 2010-15]

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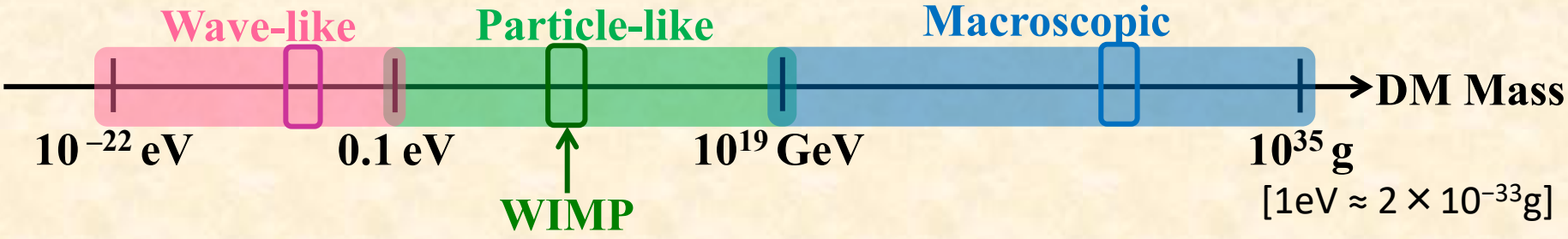

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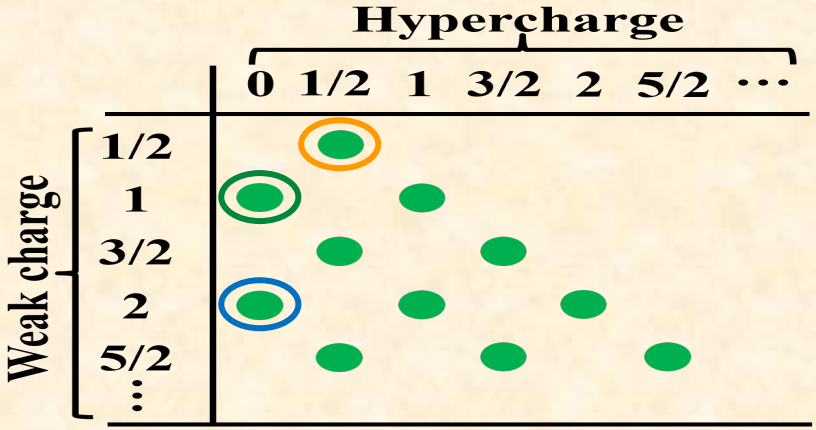

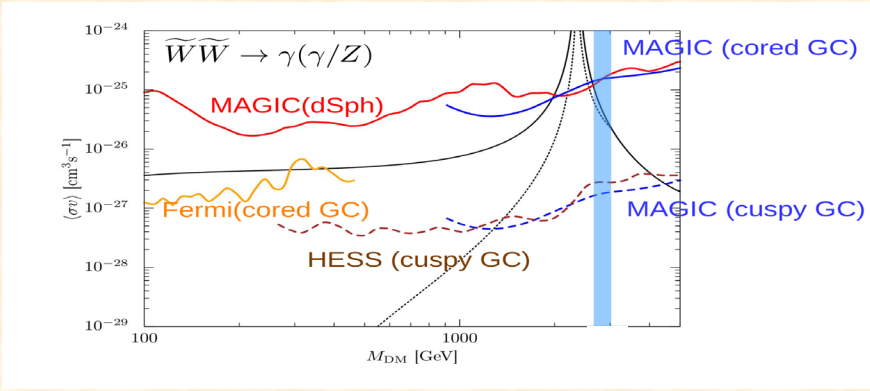

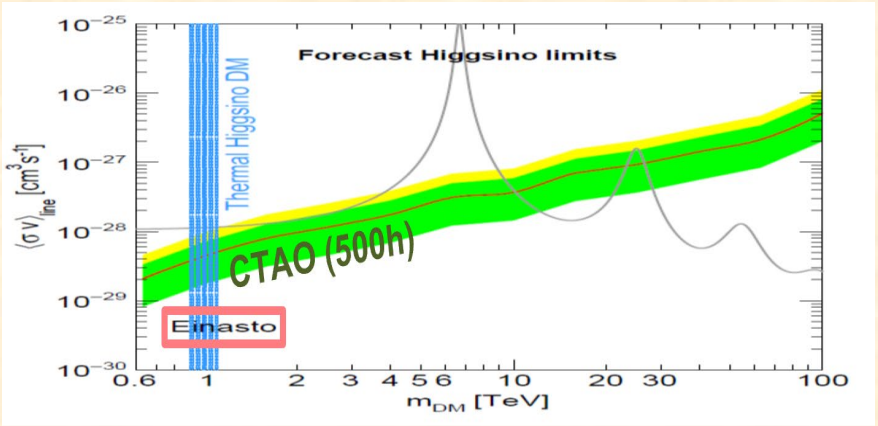

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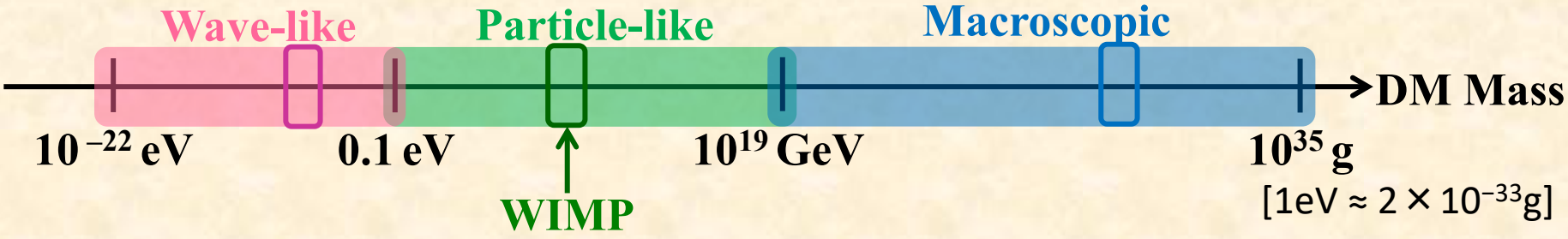

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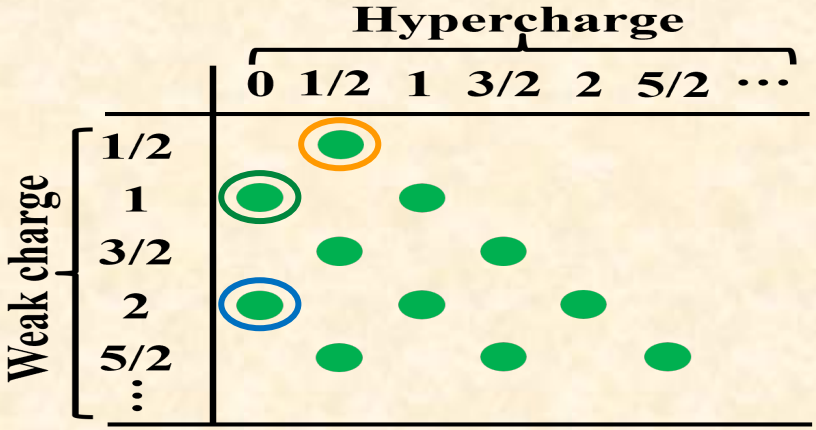

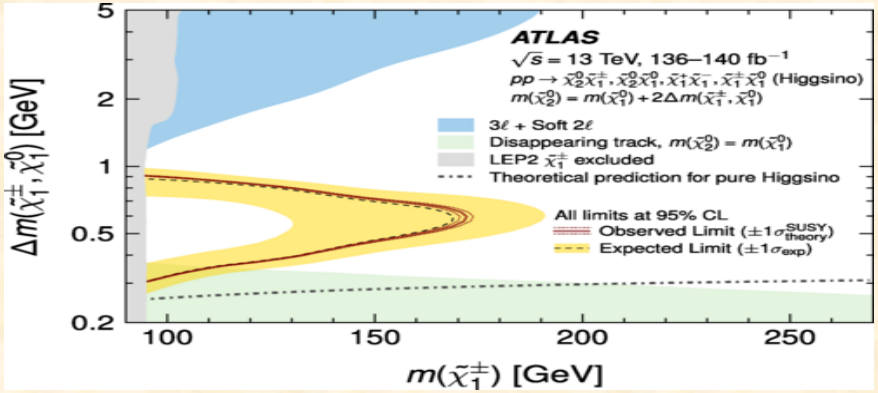

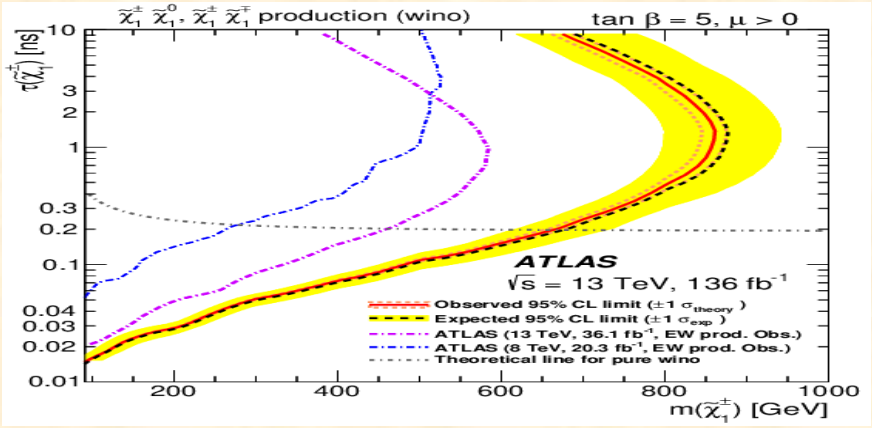

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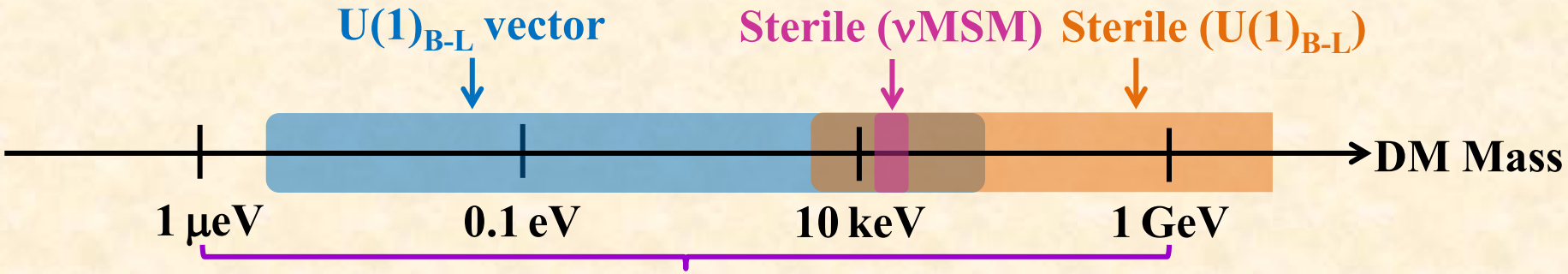
Efforts in collider-based searches.
[Ibe, S.M., Sato, 2012; S. Shirai++, 2020-24]

Light dark matter: One possible motivation



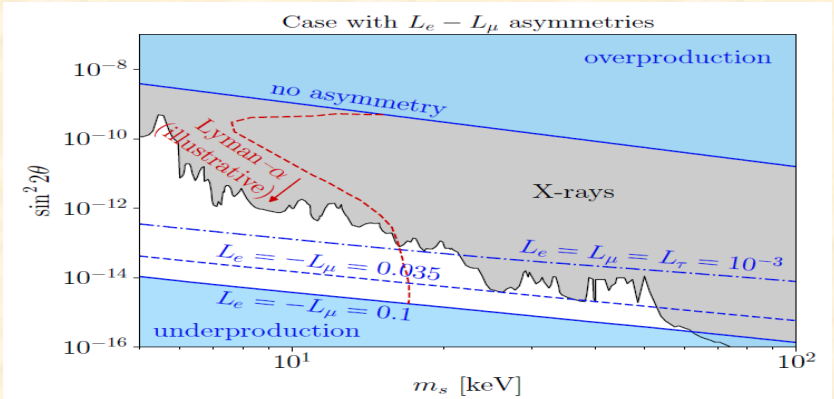
SM + R-handed neutrinos: Seesaw & Leptogenesis mechanisms

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_i \bar{N}_i \left(i\gamma^\mu D_\mu - m_{N_i}\right) N_i - \sum_{i,j} \left[y_{ij}^{(\nu)} \bar{L}_i H^c N_j + \text{h.c.}\right]$$

The minimal setup introduces *two* R-handed neutrinos.

Sterile (νMSM)

With three right-handed neutrinos:



[K. Akita, et al, 2025; K. Kasai, et al, 2025; Y. Georis, et al., 2026]

Gauged U(1)B-L extension of SM

Three N_is are naturally introduced.

The $U(1)_{B\text{-}L}$ gauge interaction allows sterile-ν DM over a wide mass range.

Tremaine–Gunn sets the lowest mass.

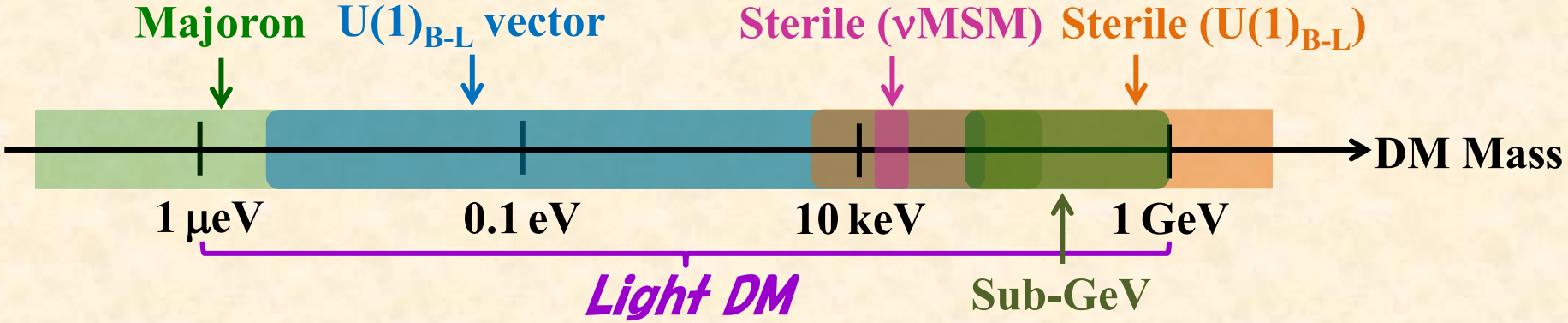
[S. Fujisawa, T. Hayashi, S. M., Y. Watanabe, 2025]

For a tiny $U(1)_{B\text{-}L}$ gauge coupling, the gauge boson itself can be dark matter.

Prod. & stability set the mass range.

[T. Hayashi, S. M., Y. Watanabe, T. Yanagida, 2025]

Light dark matter: One possible motivation



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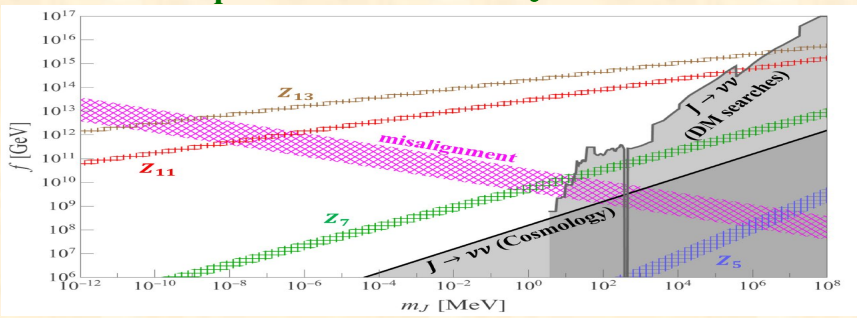
Majoron

Gauged $Z_N \subset U(1)_{B-L}$ extension of SM.
Three N_is are naturally introduced.



[S. Fujisawa, Q. Liang, S. M., M. Uwabo, T. Yanagida, 2026]

Accidental $U(1)_{B-L}$ → Majoron DM

Sub-GeV dark matter

Neutrino masses arise radiatively.
Low-scale leptogenesis explains BAU.

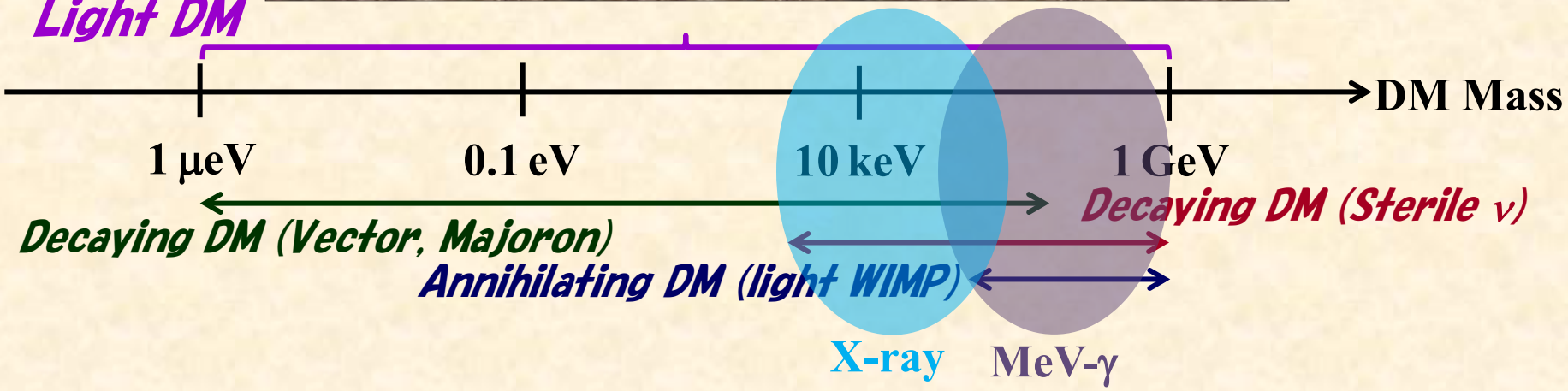
Such scenarios can accommodate sub -GeV DM (light WIMPs) naturally.

[J. Herms, S. Jana, V. P. K. S. Saad, 2023]

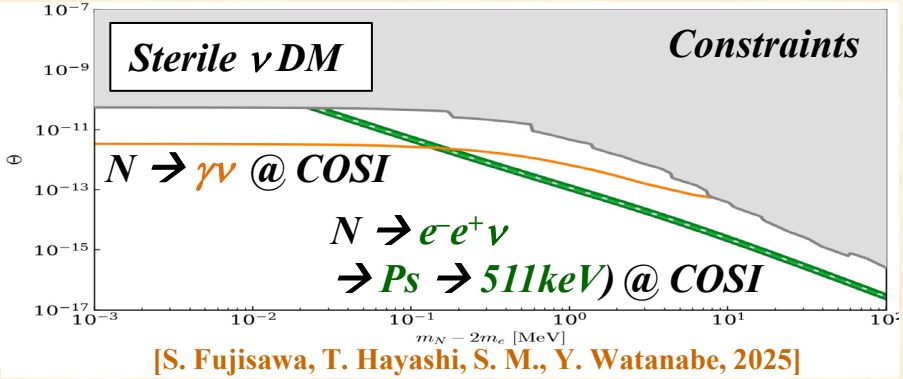
Various sub-GeV DM scenarios exist, but strong cosmological constraints must also be carefully considered.

[Y. Watanabe, S.M., et al., (COSI collaboration) 2025]

Searching for Light dark matter



New search prospects with MeV γ-ray obs. (COSI, SMILE, GRAMS):



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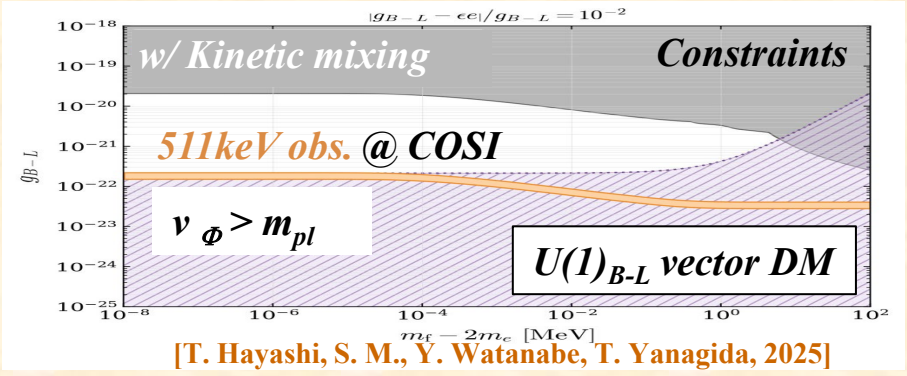

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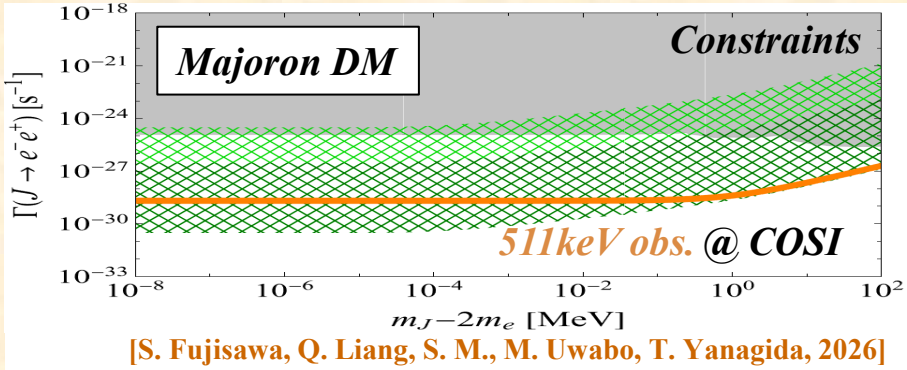

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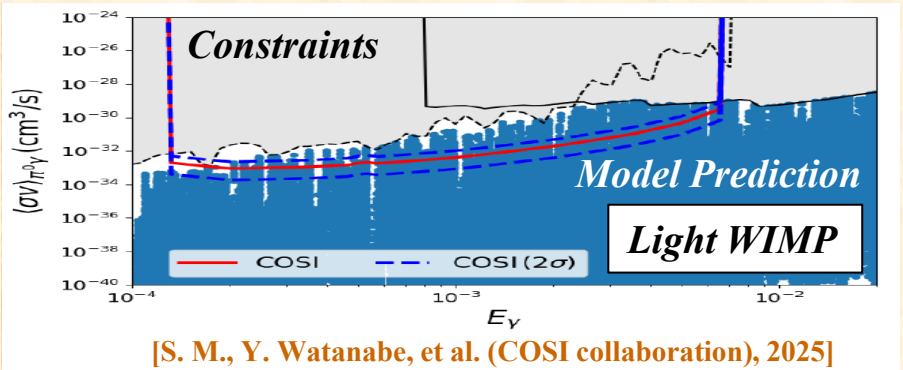
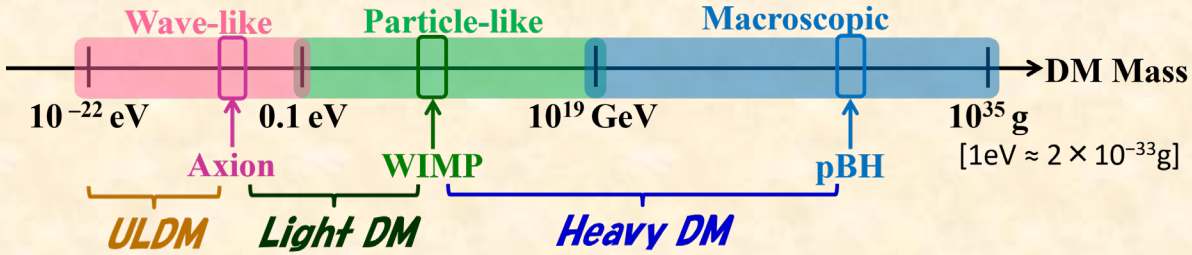


[S. M., Y. Watanabe, et al. (COSI collaboration), 2025]

Summary

We discussed particle DM candidates and their experimental searches!

- ✓ **WIMPs are well motivated by the electroweak hierarchy problem, with electroweak-charged candidates predicted in various BSM models at O(1-10) TeV. They remain promising targets for direct detection, enhanced indirect detection, and collider searches.**
- ✓ **Light DM is motivated by simple SM extensions addressing neutrino masses and baryogenesis. Right-handed neutrinos, gauged B−L or Z_N symmetries, and radiative neutrino-mass models provide sterile-neutrino, vector, Majoron, and sub-GeV DM candidates, with promising new searches using MeV γ-ray observations.**



- ✓ **For light DM below the keV scale, direct detection is increasingly important, with advancing technologies. Axions and ultralight DM remain important at even lower masses, while the region beyond the WIMP mass scale remains largely uncharted territory.**