F01

Development of spectrometer for WISP DM searches

デッドタイムフリーな暗黒物質探索用スペクトロメータdSpecの開発研究

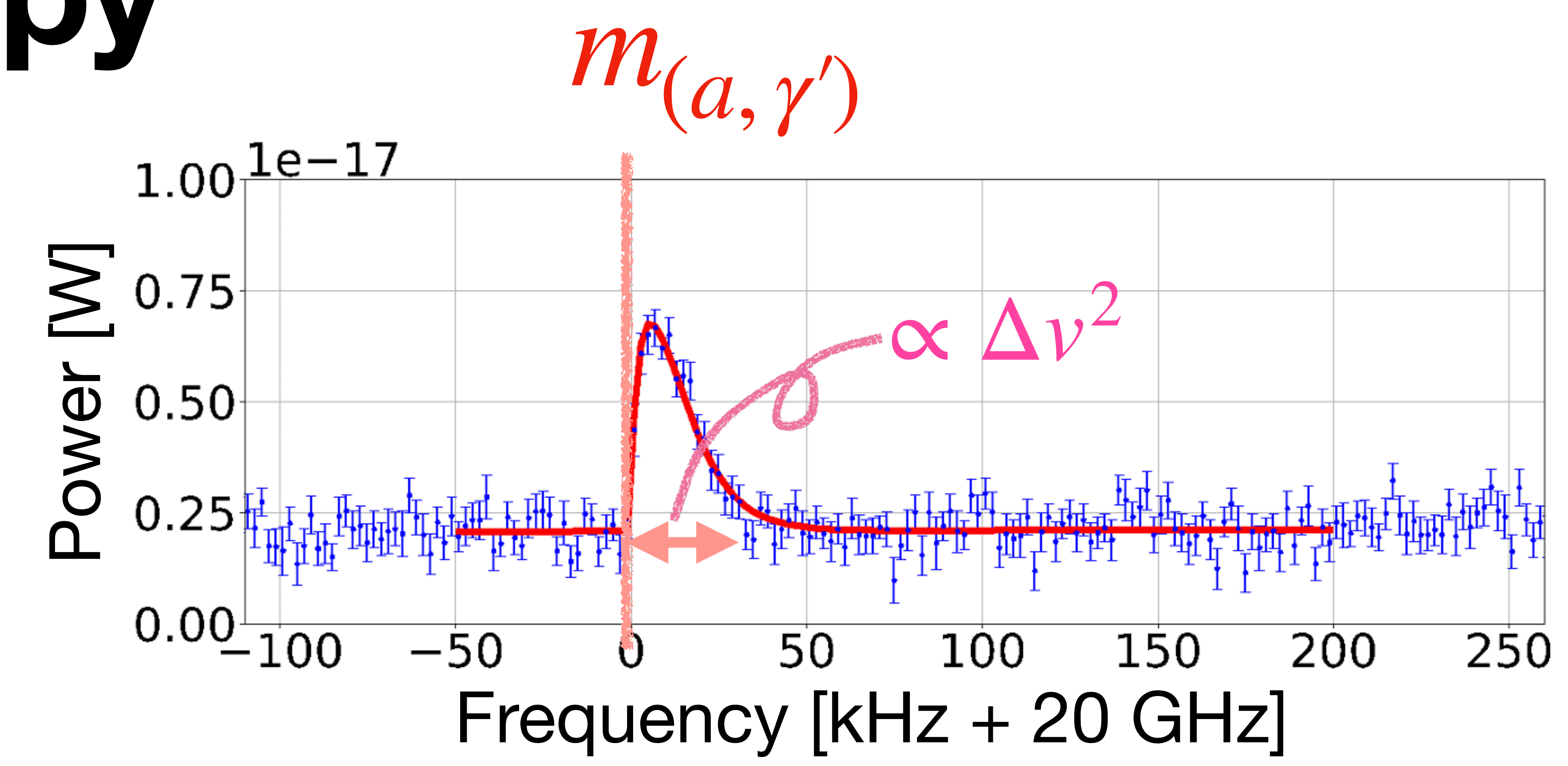
Junya SUZUKI (Kyoto U.) 2022-03-29

Dark matter spectroscopy

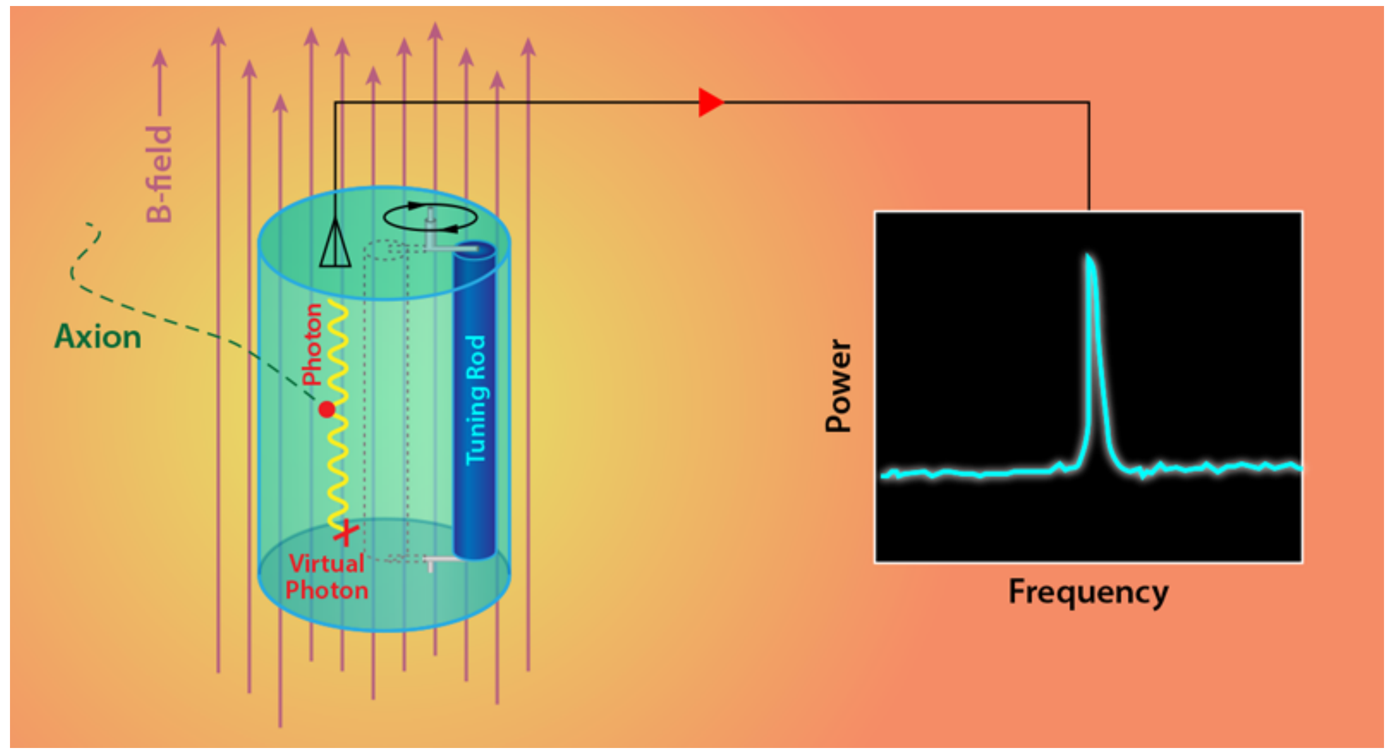
- Cold axion / dark photon leaves spike at

$$\omega = m_{(a,\gamma')}$$

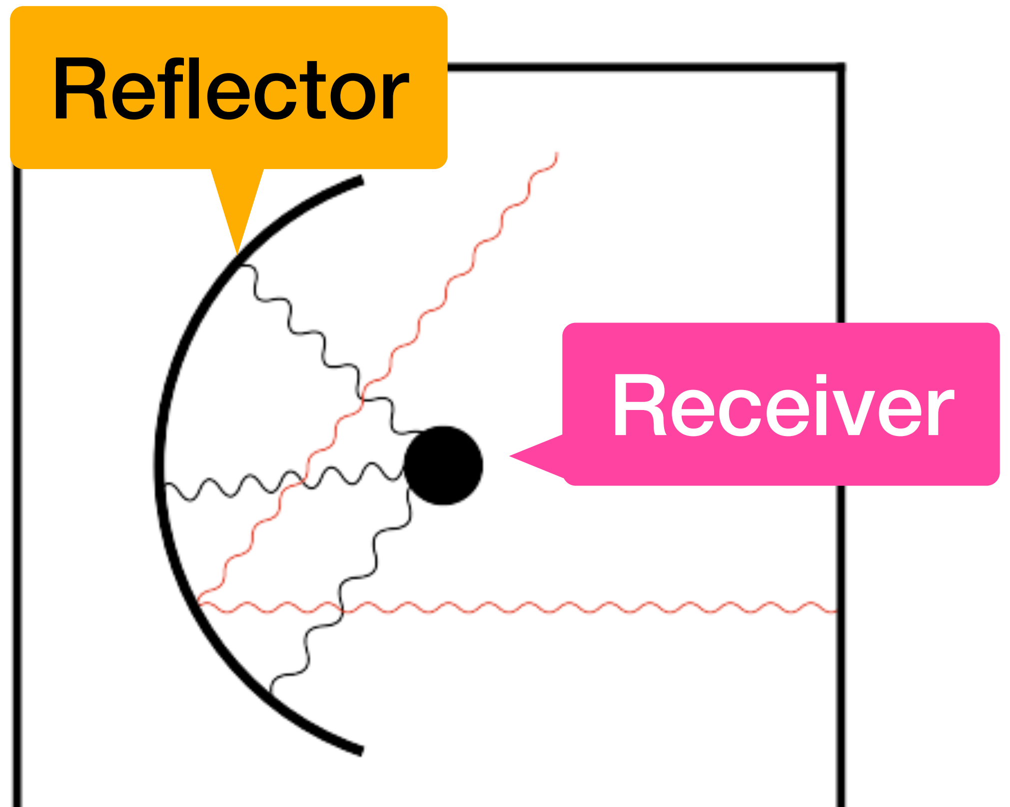
  in spectormeter.



- Cavity experiment:
  - High Q cavity
    <=> Narrow mass region coverage
- Dish type search
  - Wide search in principle
  - Wide bandwidth spectrometer needed



C. Boutan/Pacific Northwest National Laboratory; adapted by APS/**Alan Stonebraker**



D. Horns *et al* JCAP04(2013)016

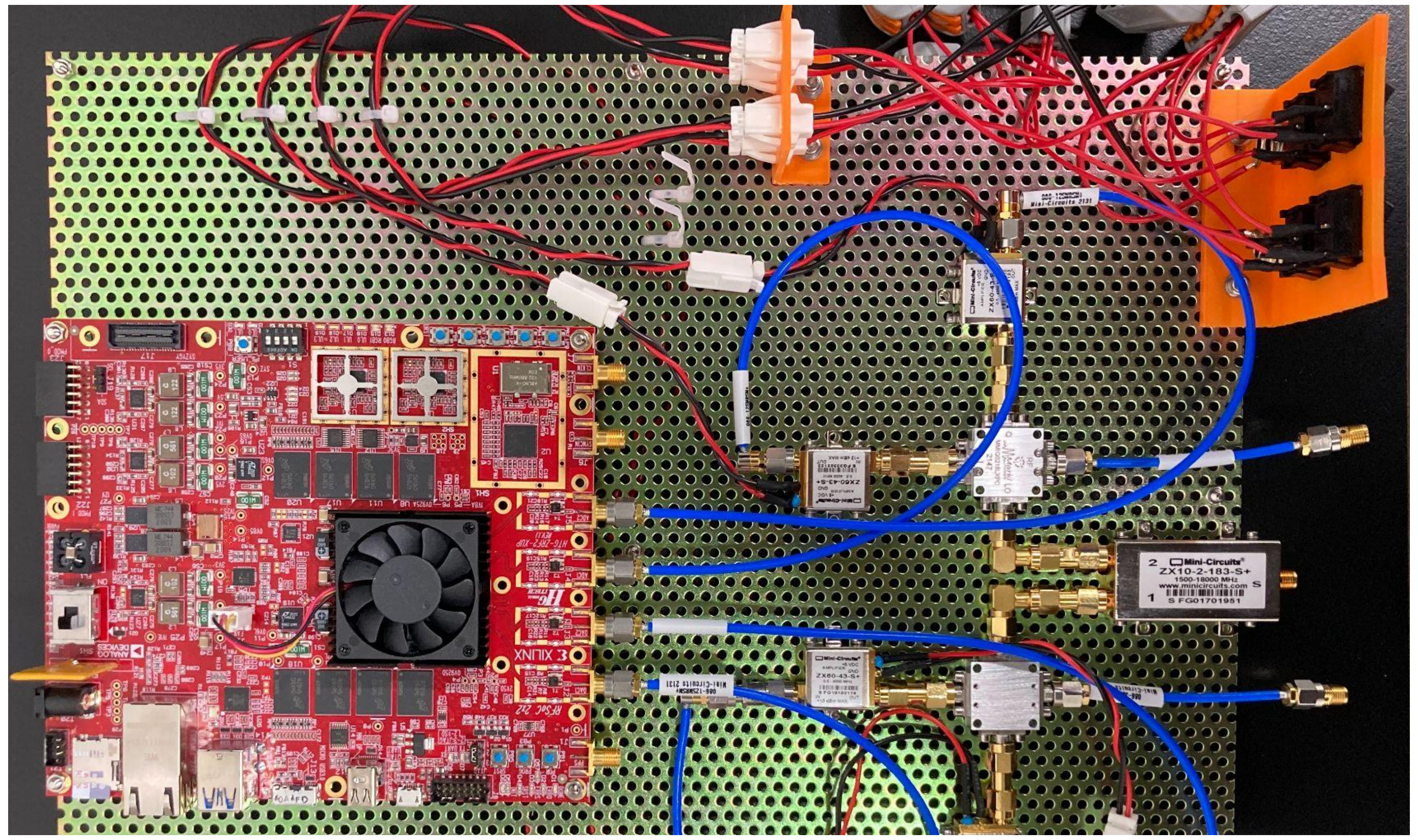
dSpec **project**

Spectrum/signal analyzer

Commercially available SPA/SA

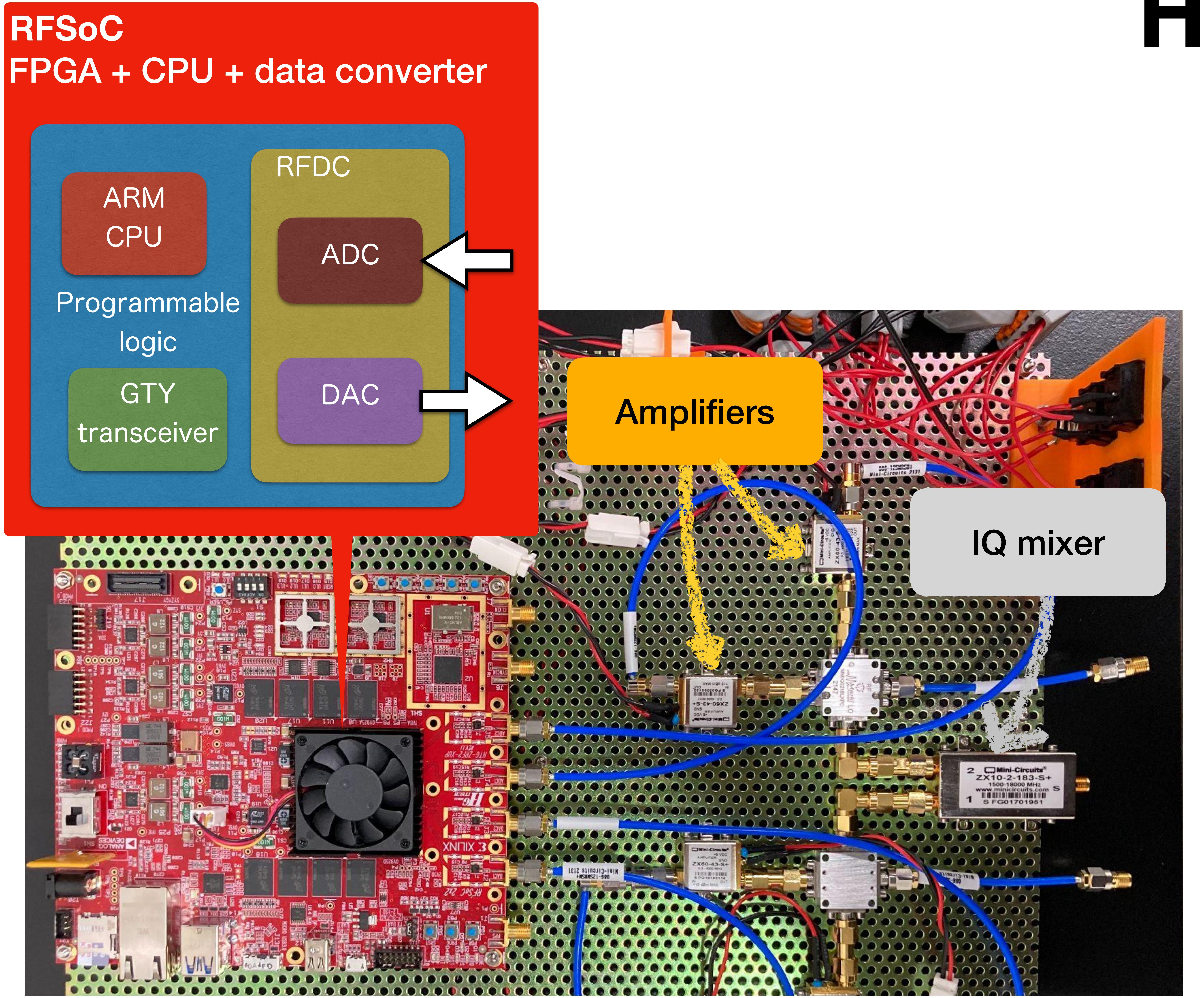
- **Narrow bandwidth, 99% overhead**
- Blackbox inside
- Incredibly expensive

dSpec



- **GHz bandwidth, dead-time free**
- Open source
- ~ 300 k JPY (digitizer)

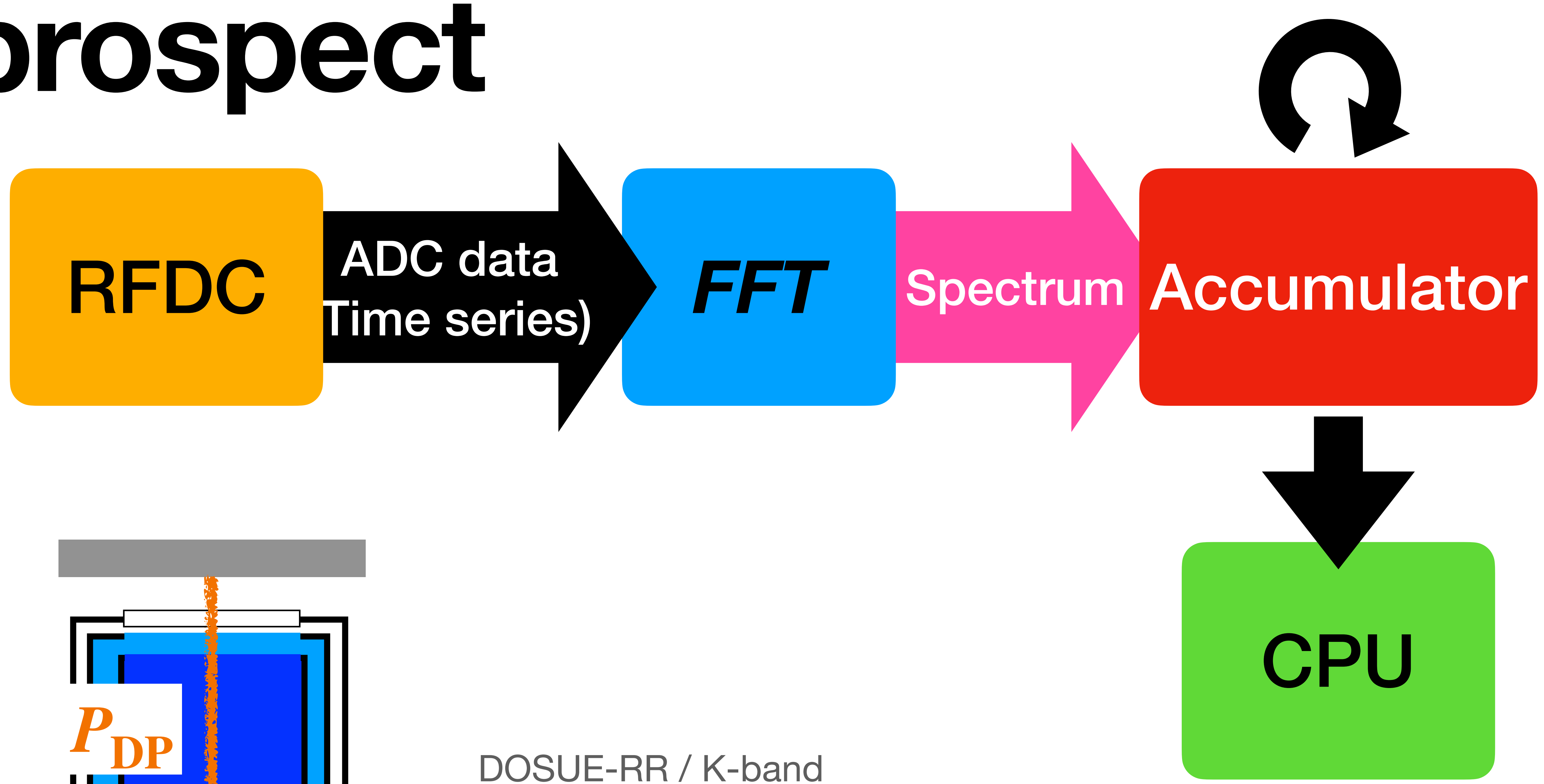
Hardware of *dSpec*

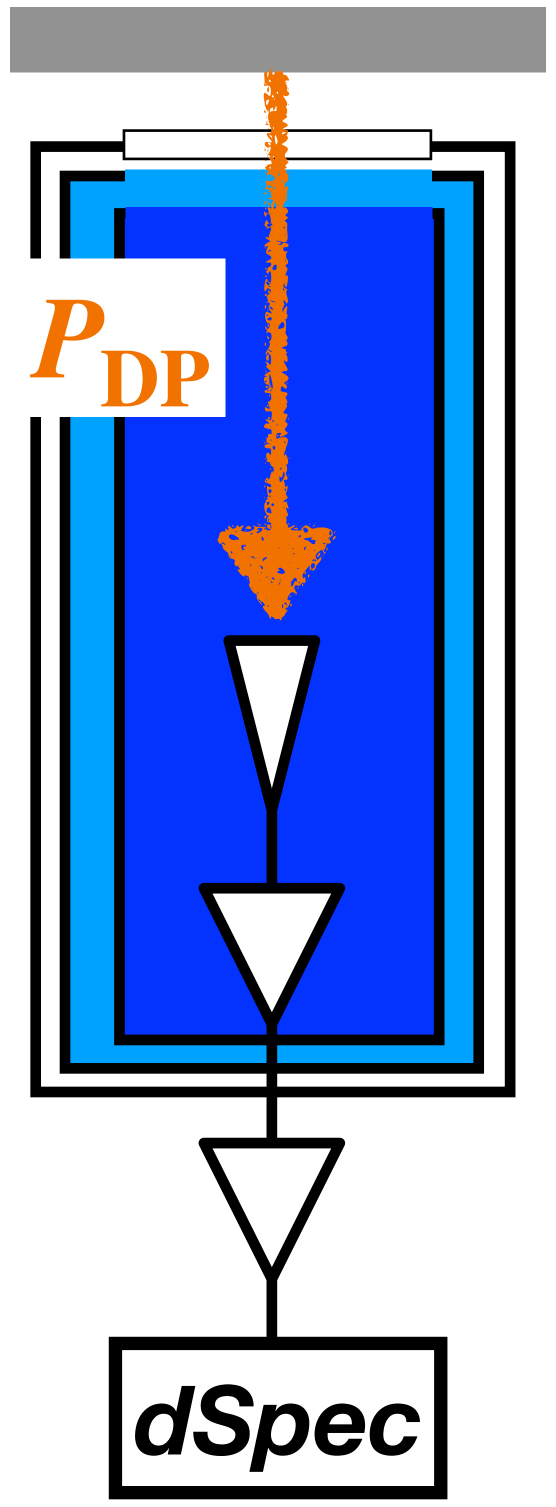


- RFSoC (System on Chip)
  - Data converters and logic fabric integrated
  - High performance / hardware simplification
- Spin-off from readout for superconducting sensor
  - Data receiver will be used for *dSpec*

Next to do / Future prospect

- Implementation of firmware
    - FFT on RFSoC PL
    - Data accumulation
- Performance characterization
- Application to DP/axion search





DOSUE-RR / K-band

F02

Detection experiment of dark-matter-axion microwave emitted from superconductors
超伝導体から放出される，暗黒物質アクシオン由来電磁波の検出実験

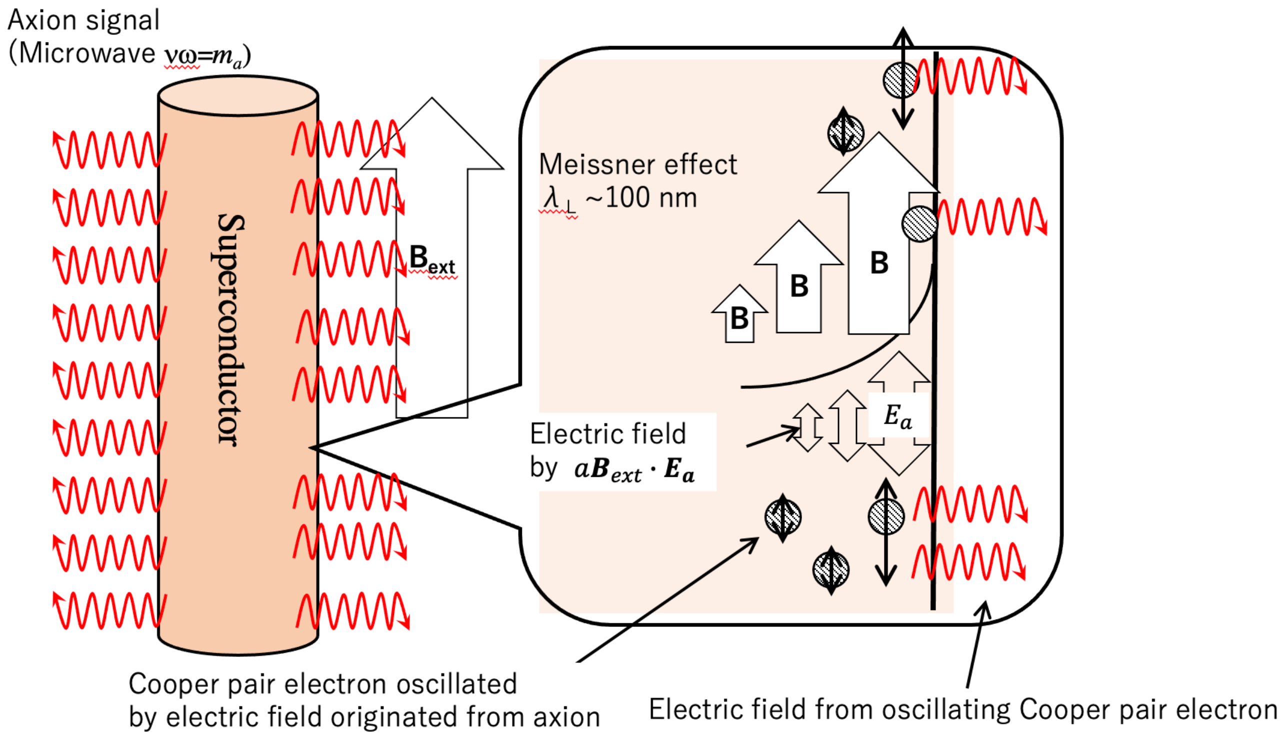
March 29th, 2022

Yasuhiro Kishimoto

Axion signal from SC in strong magnet

- Axion is emitted from metal surface in a magnetic field.
- It is pointed out large enhancement of axion signal from superconducting surface in strong magnetic field due to the collective motion in the media.

$$P = 4.4\times10^{-18}\,(\mathrm{W})\left(\frac{8\times10^{-8}\ \mathrm{m}}{\lambda}\right)^2\left(\frac{B}{5T}\right)^2\left(\frac{R}{1\ \mathrm{cm}}\right)^2\left(\frac{L}{10\ \mathrm{cm}}\right)^2\left(\frac{k_a}{1.0}\right)^2\left(\frac{\rho_a}{0.3\ \mathrm{GeV/cm^3}}\right.$$

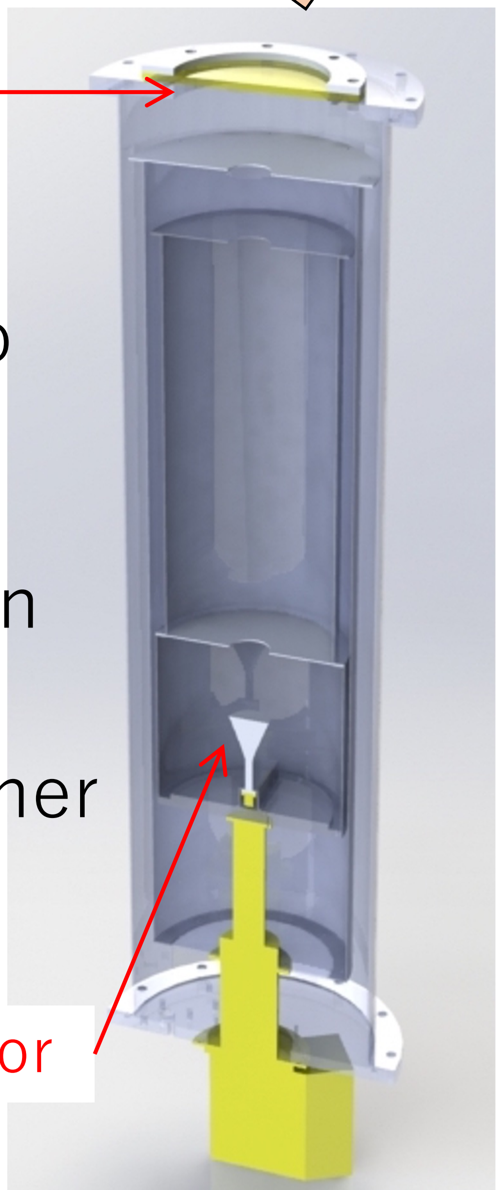


~10^4 enhancement

But we revisit the idea and found no such enhancement.
(YK and K. Nakayama, 2022)

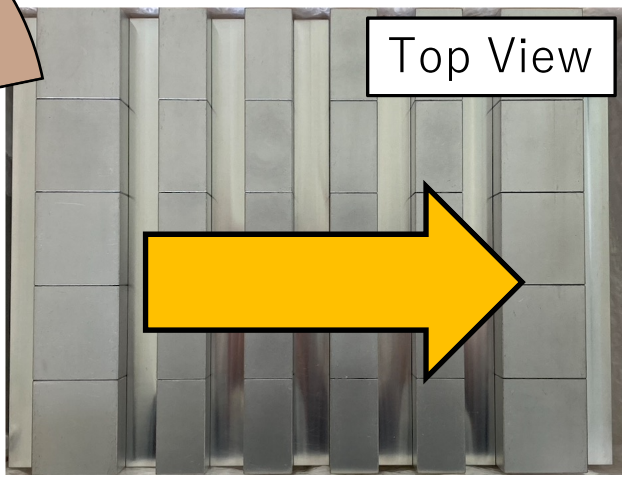
https://doi.org/10.1016/j.physletb.2022.136950

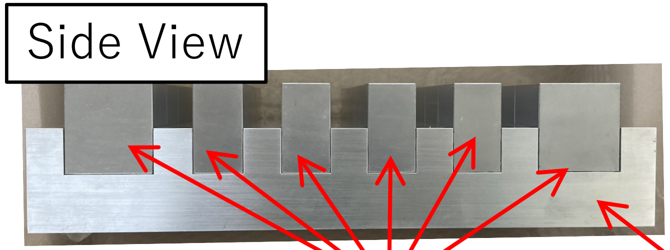
The apparatus



DOSUE

- Developed by Kyoto University group
- Search for DM dark photon by putting on metal plate
- 20~30 GHz and higher





Active area

20 mm width
125 m length x 5
(24 mm depth)
B =0.7 T

Metal plate with permanent magnet

- Newly developed for axion DM combining with DOSUE.

- Future extensions
  - 9T, ϕ 110 mm solenoid in RCNS
  - There is a huge stronger solenoid-magnet filed apparatus in NIFS.
    - 13 T, ϕ 700 mm
  - We need to consider arrangement of metal plate and antenna in the cryostat, but they can be utilized in the future experiments.

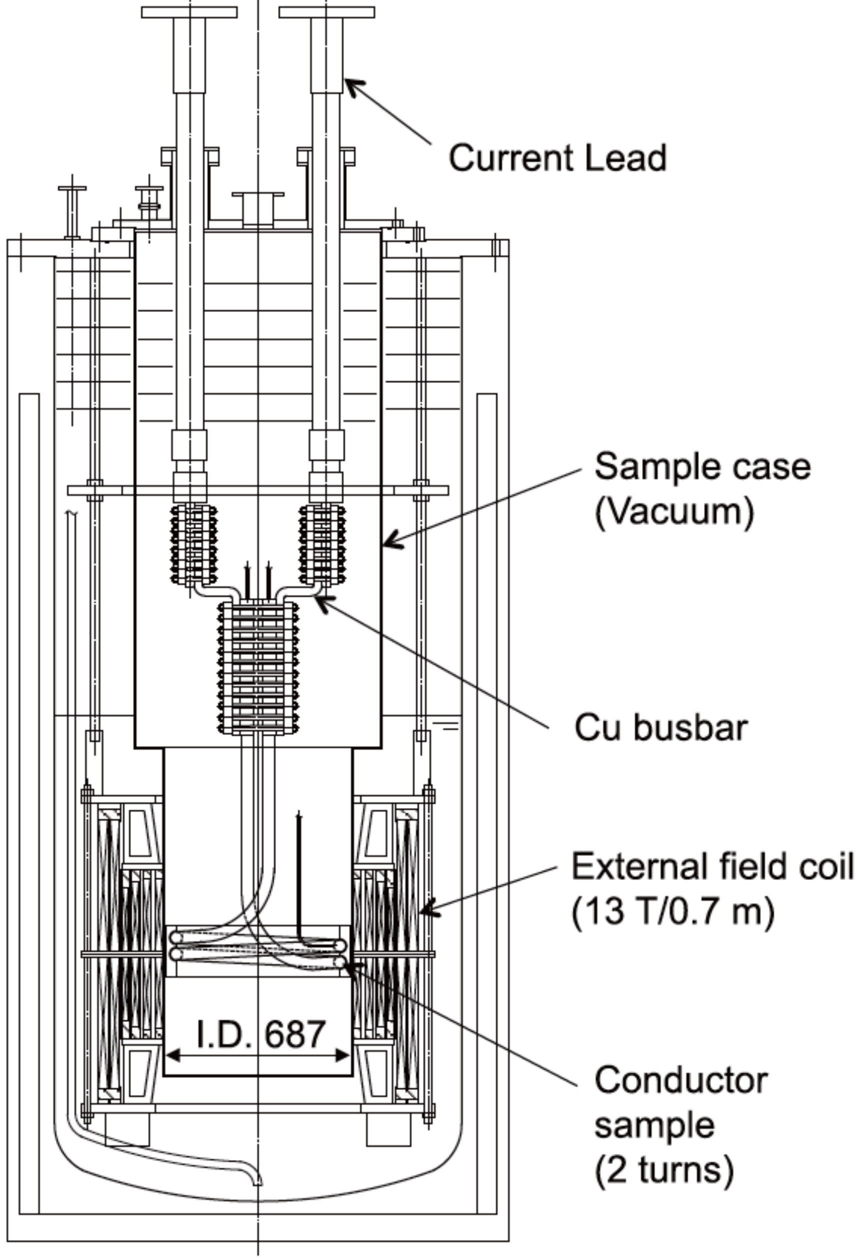
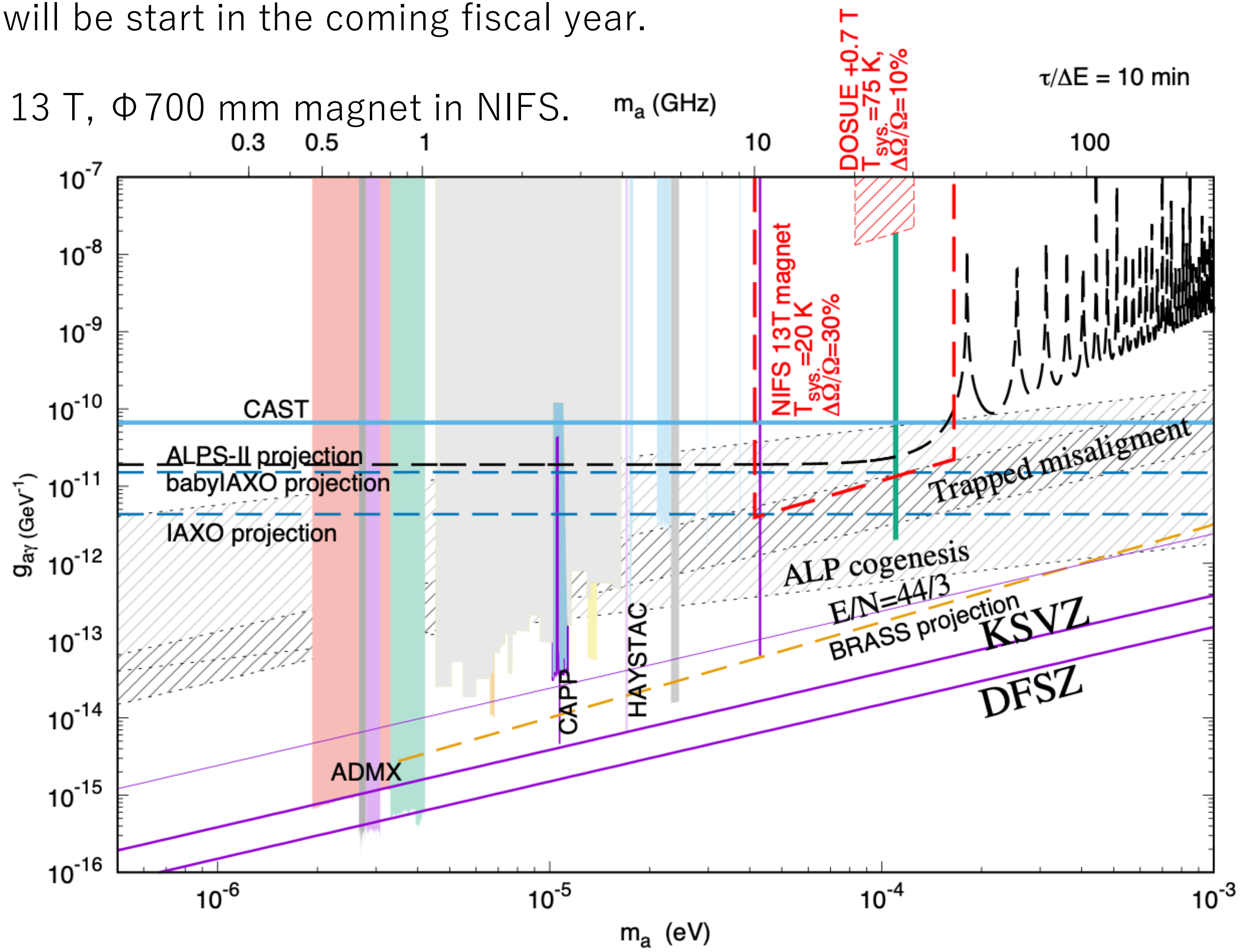


Fig. 2 Setup of the new test facility with the 13 T - 0.7 m external field coil and a conductor sample.

- Experiment DOSUE + will be start in the coming fiscal year. (Red hatch)
- Future experiment with 13 T, Φ700 mm magnet in NIFS.



F03

Probing the nature of dark matter in galaxy scales

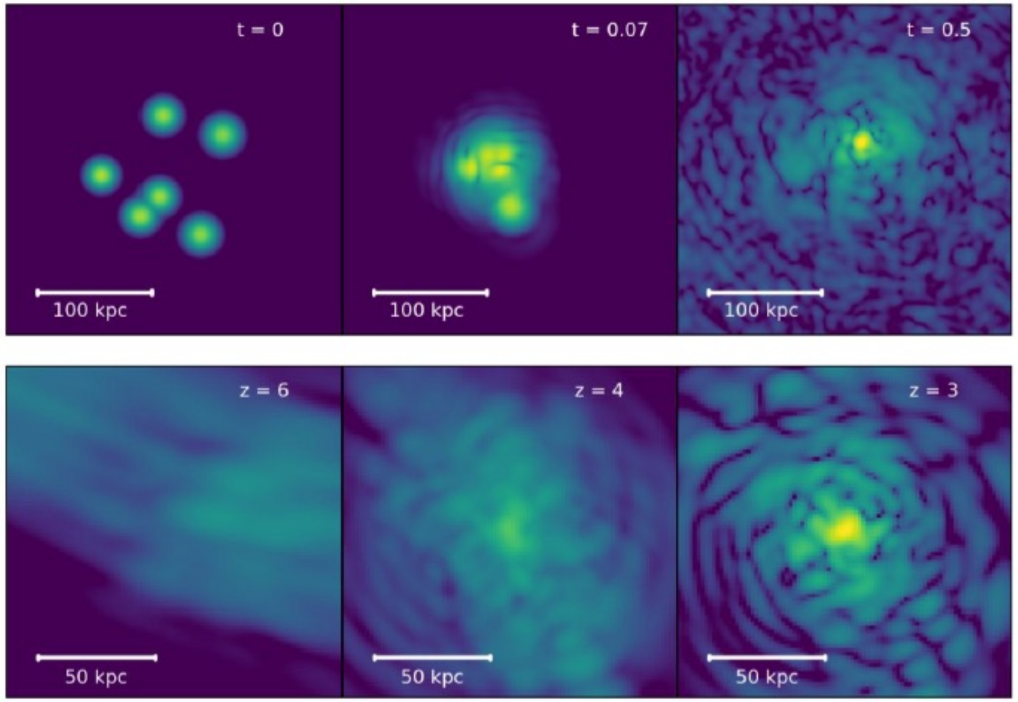
Masashi Chiba (Tohoku Univ)
公募研究者

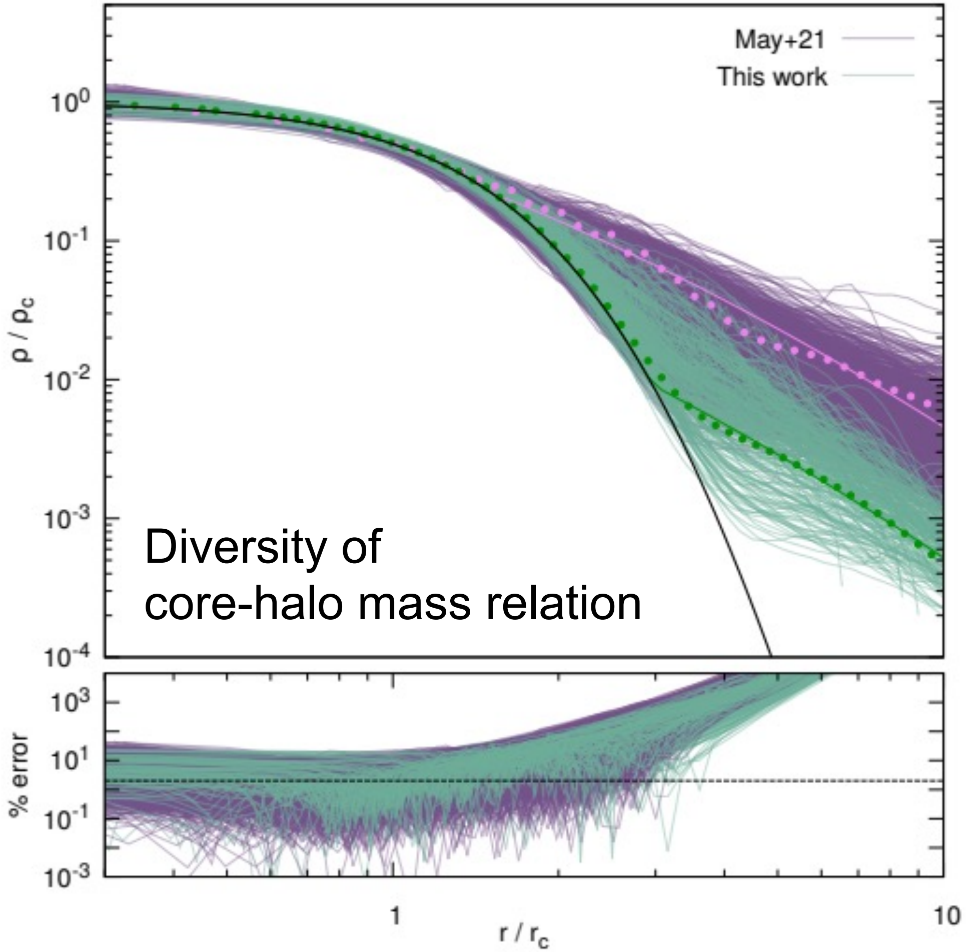
1. The diversity of core-halo structure in the fuzzy dark matter model
2. Jeans analysis of dwarf satellites based on high-order velocity moments

The diversity of core-halo structure in the fuzzy dark matter model

Jowett Chan (D3), Ferreira, May, Hayashi, Chiba, 2022, MNRAS

m = 1 x 10^{-22} eV/c^2





This diversity needs to be considered for DM measurements in dwarf satellites!

Jeans analysis of dwarf satellites based on high-order velocity moments

Dafa Wardana (M2), Chiba, Hayashi

Core/cusp problem in dwarf satellites

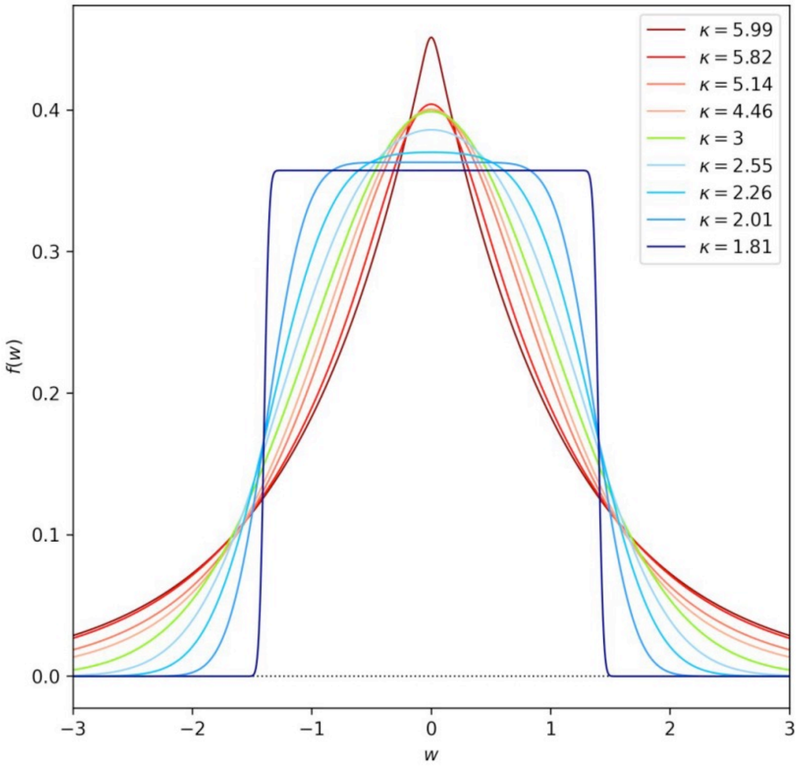
Need to break the mass-anisotropy degeneracy in the 2nd-order Jeans analysis of V_{los} distribution by analyzing the 4th-order velocity moment – our goal!

4th order velocity moment:

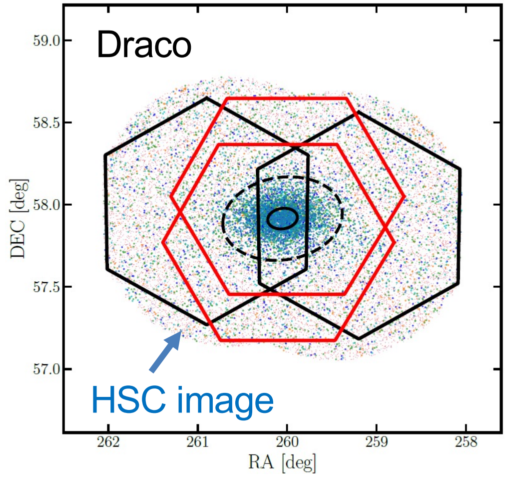
$$\overline{v^4} = \int dv\,(v - \bar{v})^4 f(v)$$

Kurtosis:

$$\kappa = \frac{\overline{v^4}}{(\sigma^2)^2}$$



Application of this method to Subaru/PFS data
⇒ DM profile



This non-Gaussianity in V_{los} provides velocity anisotropy and thus the most likely DM profile!

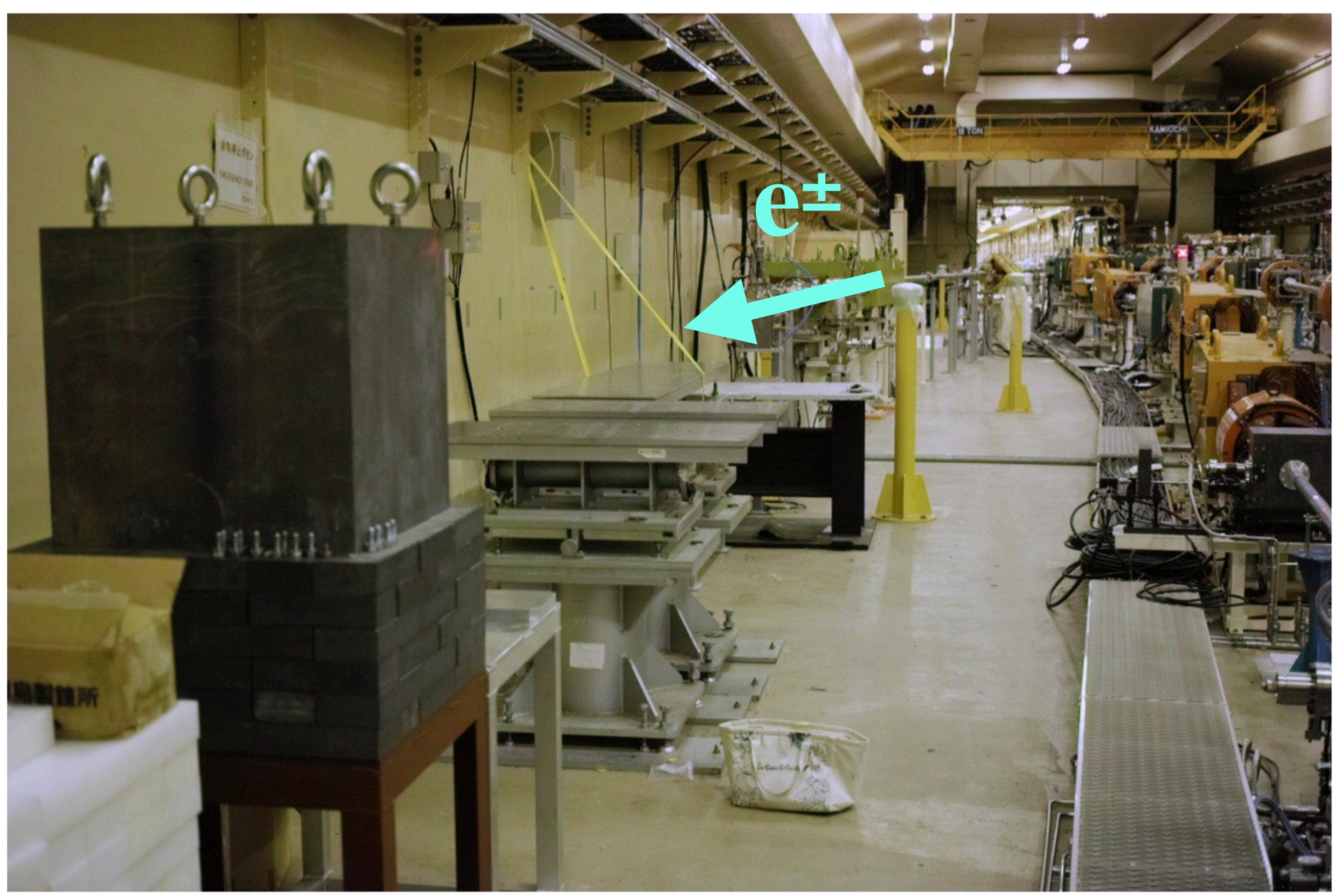
F04

Search for weakly interacting particles in KEK beam dump experiment

Yasuhito Sakaki
(KEK Radiation Science Center)

Akimasa Ishikawa (KEK), Yosuke Takubo (KEK), Tomoya Iizawa (U. Geneva), Hiroshi Iwase (KEK), Hideyuki Oide (Tokyo Tech)
Hidetoshi Otono (Kyusyu), Fusashi Miyahara (KEK), Taikan Suehara (Kyusyu), Keisuke Yoshihara (Nagoya), expanding...

We are planning a beam dump experiment in the 3rd beam switchyard at KEK Licac

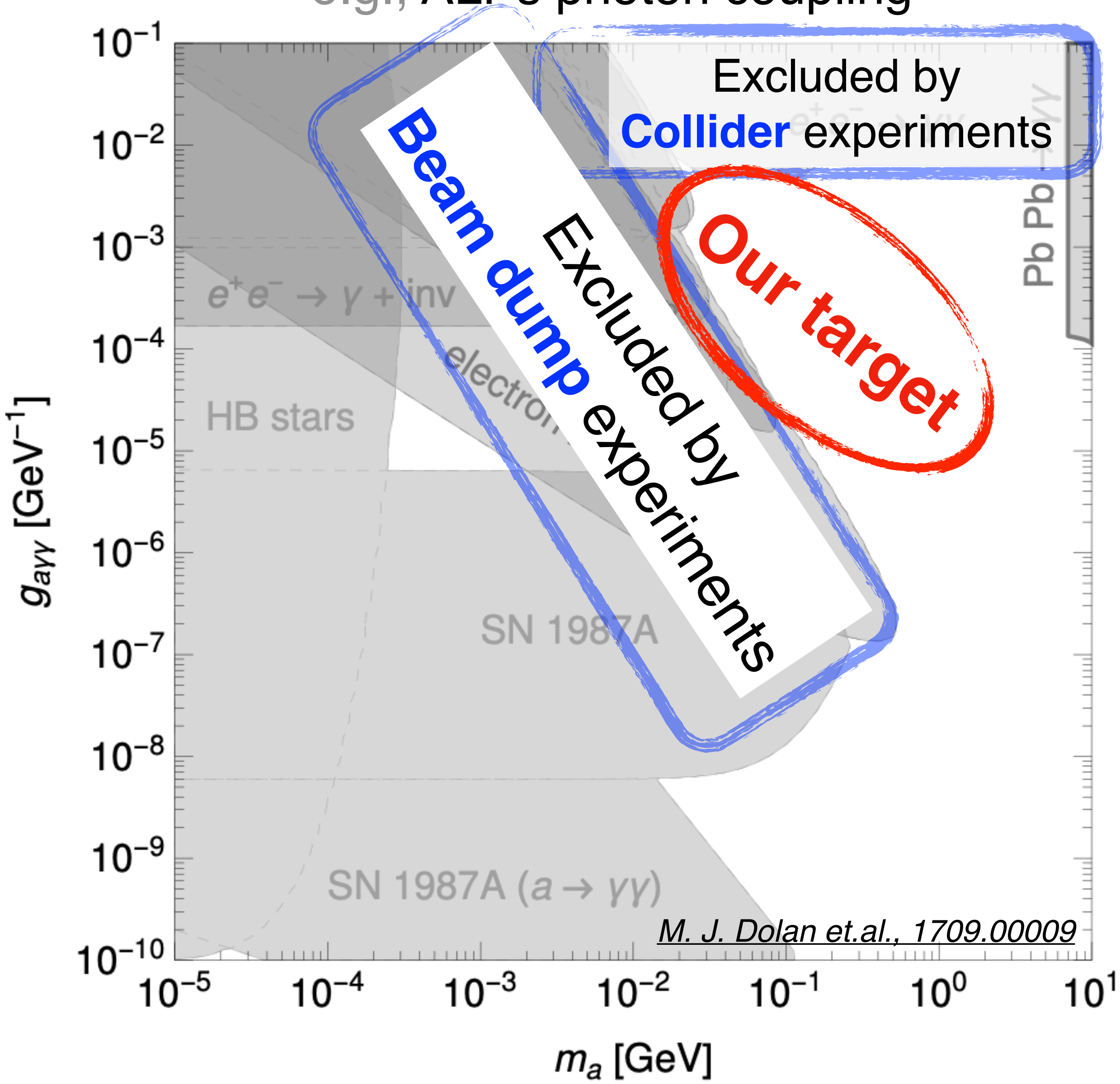


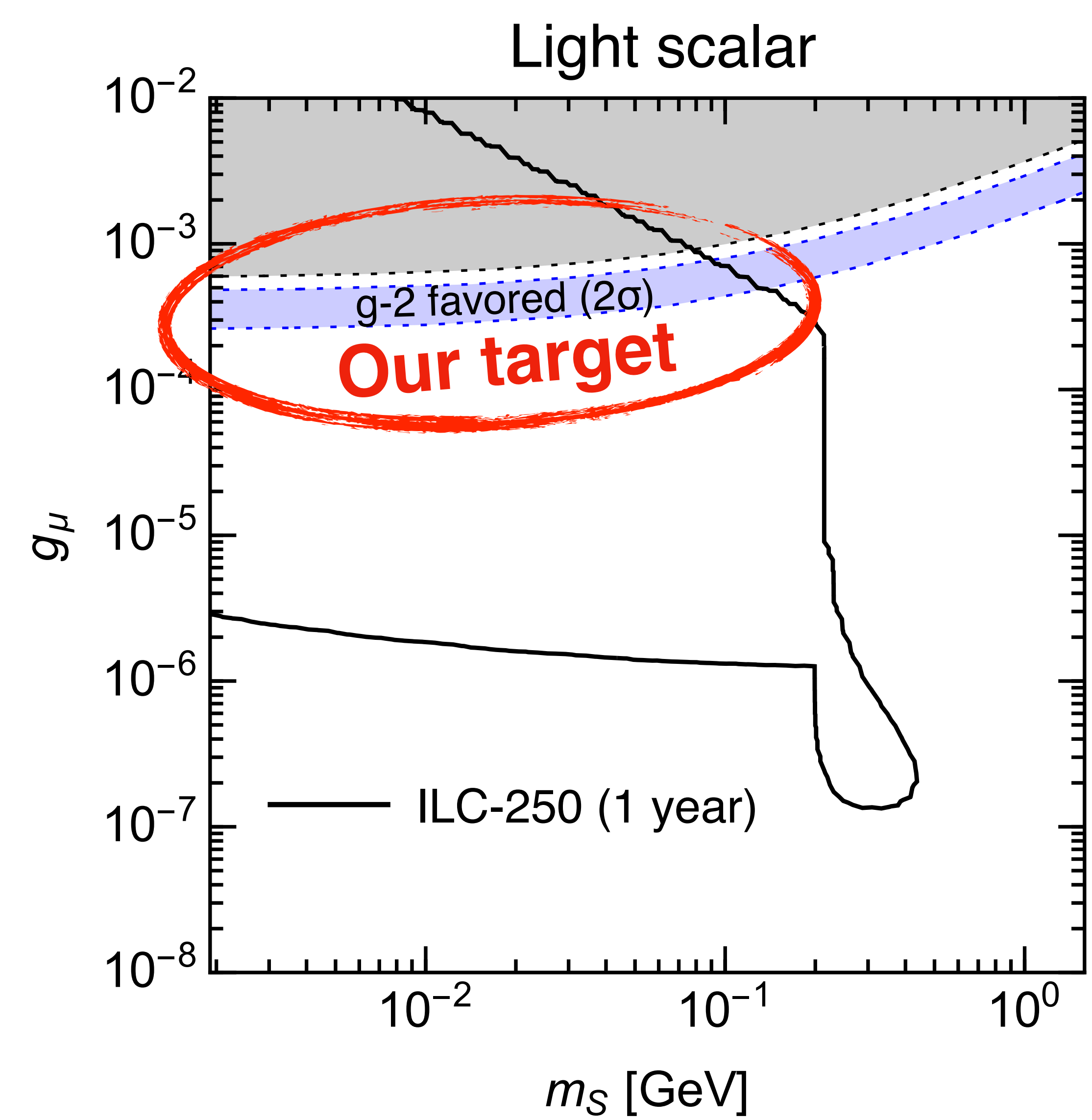
Search for MeV-GeV particles in "**short**" beam dump experiment

Unexplored region between "Collider" and "Beam dump"

Search for regions favoured by muon g-2 anomary using muons in electromagnetic showers.

e.g., ALPs photon coupling

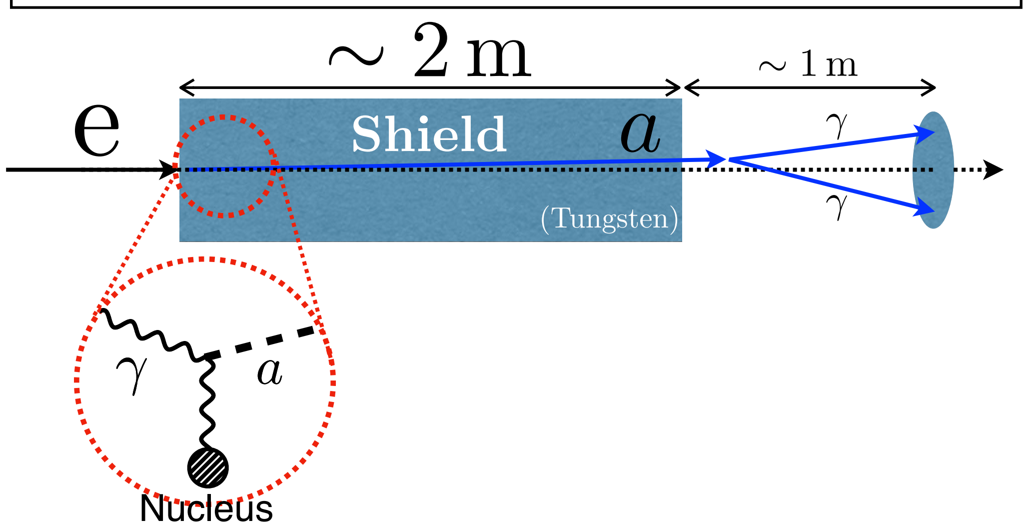




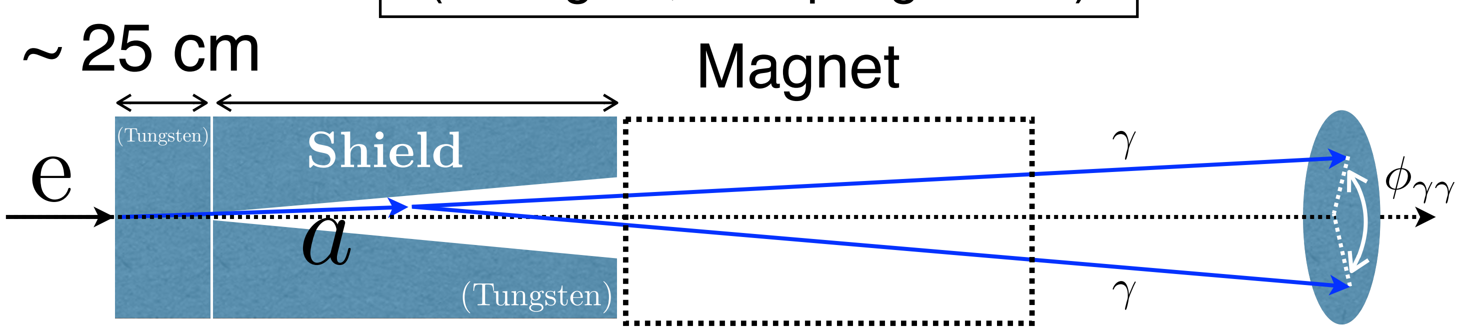
Estimation of ALPs sensitivity for two shielding setups

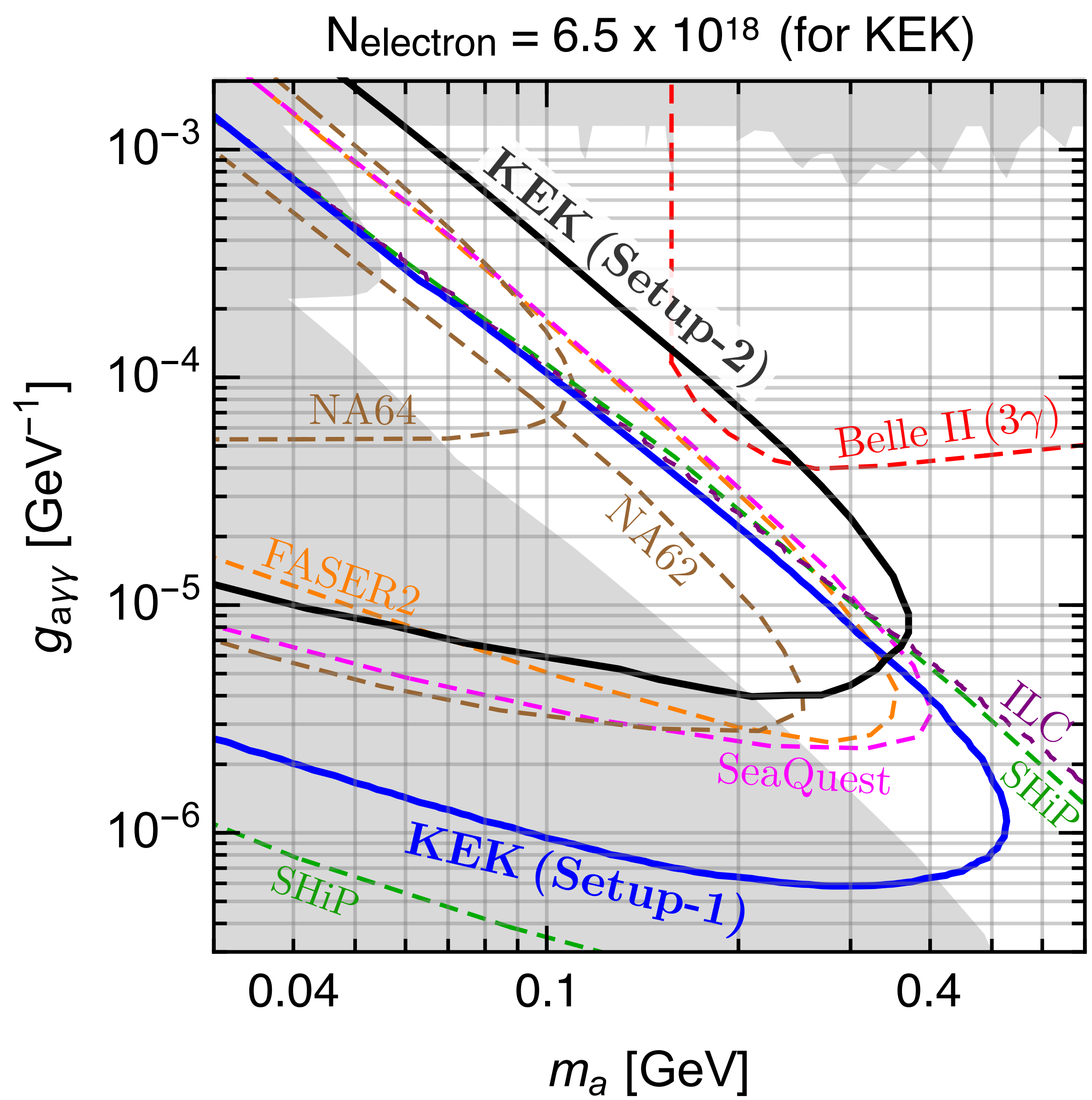
A. Ishikawa, YS, Y. Takubo, arXiv: 2107.06431

Setup-1: Simple shield setup
(→ zero-BG)



Setup-2: Short shield
(+ Magnet, Sampling ECAL)





- Electron beam experiments would give better results than proton beam ones due to less background
- Complementary to B05 activity (Belle II)

Schedule
(Opportunities to use beam time)

- 2022 July 8 or 9:

  Test experiment (Background study. $N_{EOT} = 10^{15}$-10^{16})

- 2022 Fall - 2023 Summar:

  SuperKEKB Long shutdown (Phase-1 of the beam dump experiment)

- 2023 Summay or Fall:

  Septum magnet installed upstream of the experimental beam lime.

  ➡ This allows parallel experiments using extra bunch time, even during SuperKEKB operation.

  Note: We will never take away SuperKEKB beams.

Current status

- The following are underway for the test experiment:
  - Simulation study (detector simulation, shield and beam condition optimization)
  - Checking and selecting PbO calorimeters
  - DAQ system
  - Securing necessary items

TOPAZ at TRISTAN

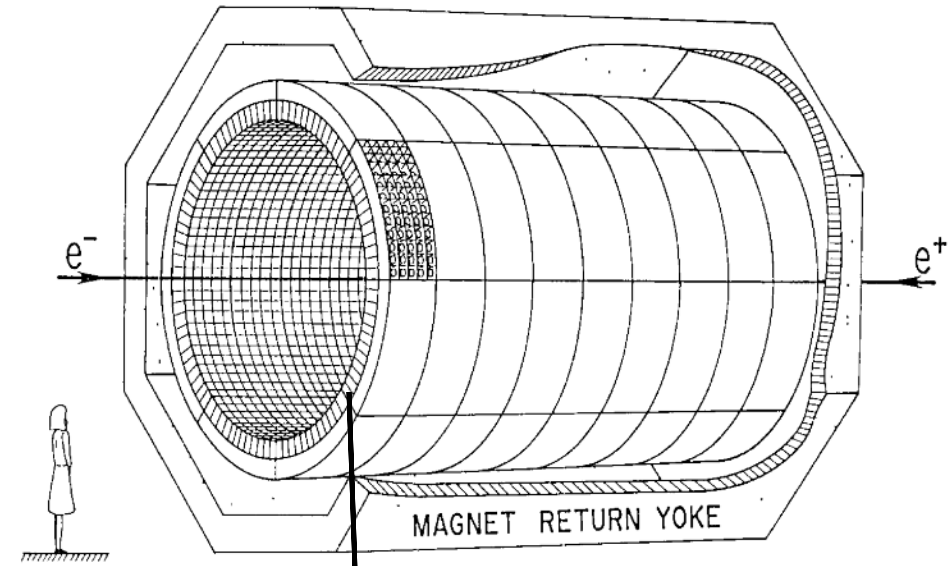
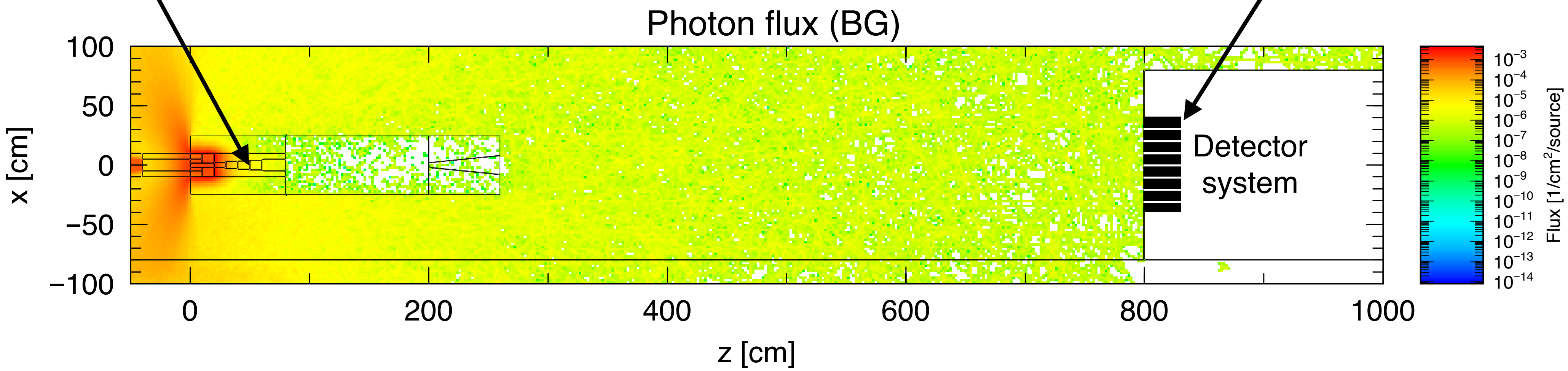


Fig. 2. Schematic view of the TOPAZ barrel electromagnetic calorimeter.

Reuse of TOPAZ PbO calorimeters

The core of the shield (tungsten) is purchased in this budget (thank you!!).



F05

Particle Physics Properties of DM probed by gamma-ray, LSBGs and IGM

GAKUHEN-A DM SYMPOSIUM

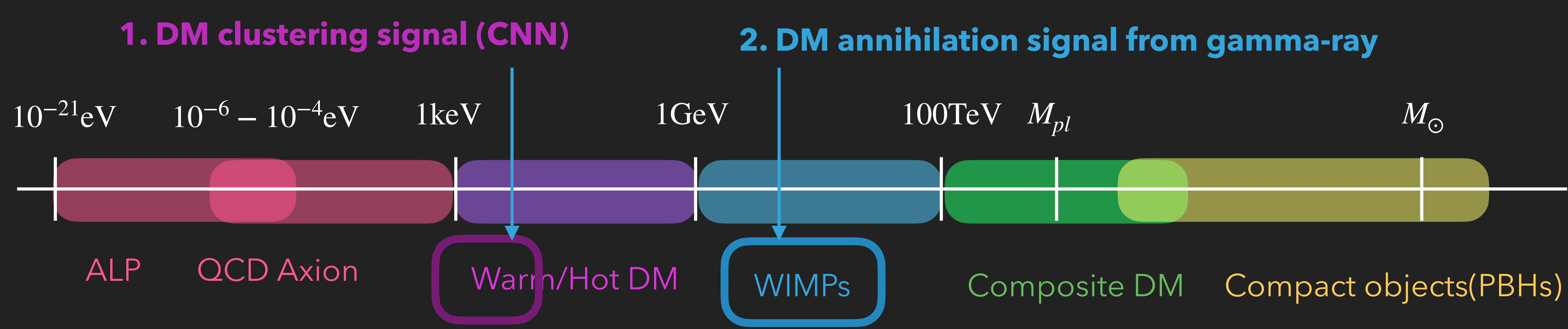
ATSUSHI J. NISHIZAWA

collaborators

D. Hashimoto, K. Murakami (Nagoya), M. Takada (Kavli IPMU), Oscar Macias (Amsterdam), K. Nagamine (Osaka), I. Shimizu (Shikoku-Gakuin)

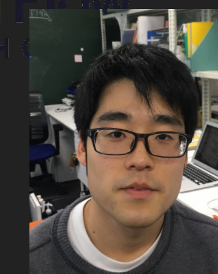
Hashimoto AJN+ 2021 [2109.08832]

Hashimoto AJN+ 2022 [2202.01400]

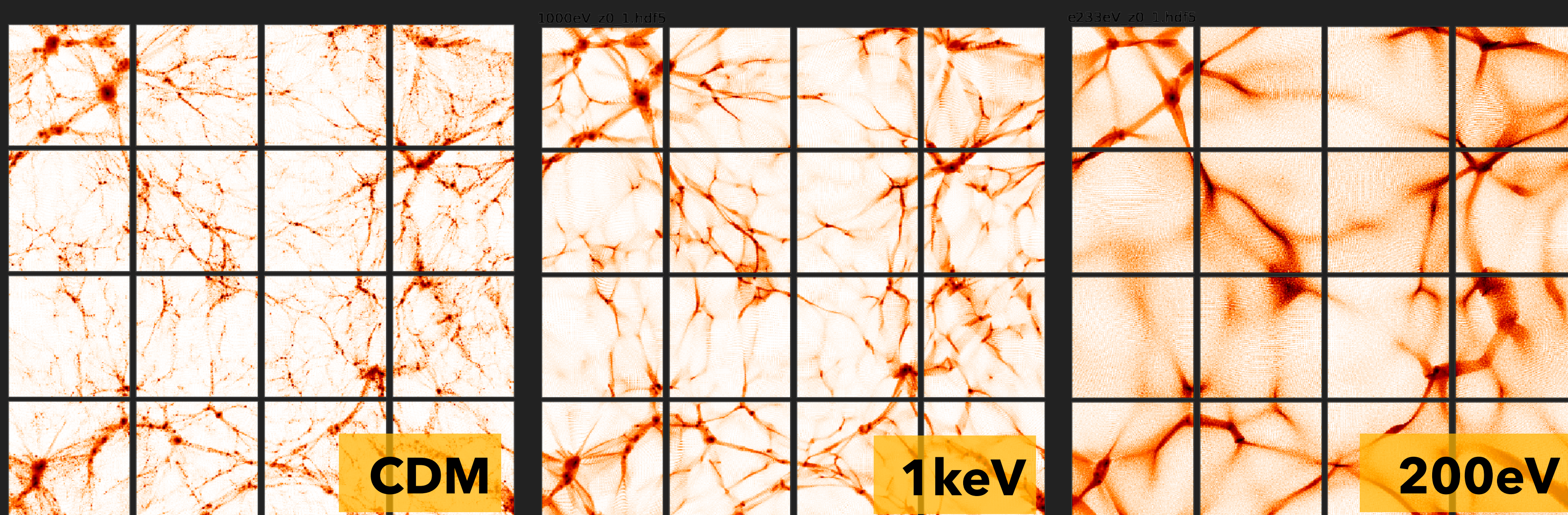


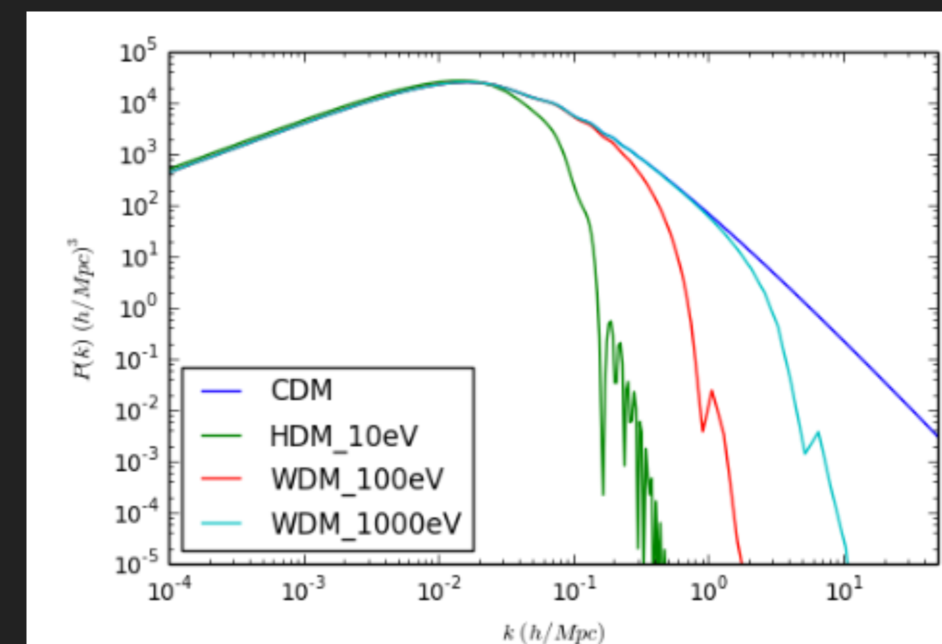
DM CLUSTERING SIGNAL : BEYOND P(K)

- use publicly available code TensorFlow (Google)
- 780k images for training and validation for every mass of dark matter
- 18 convolution and pooling layers, and 2-fully connected layers
- alleviate overfitting: 700 mini-batch, dropout layers with p=0.1
- optimization : back-propagation with Adam

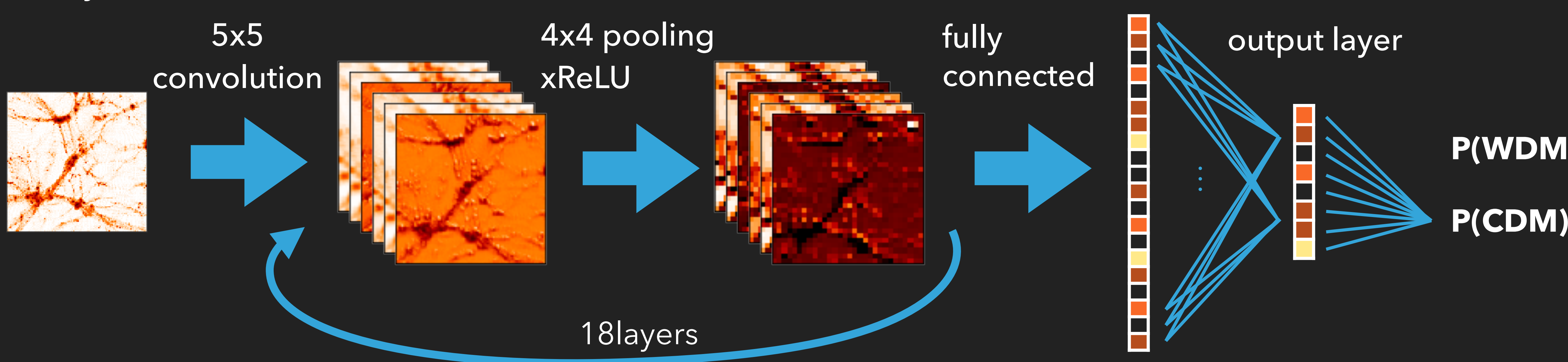


Murakami (D1, Nagoya)

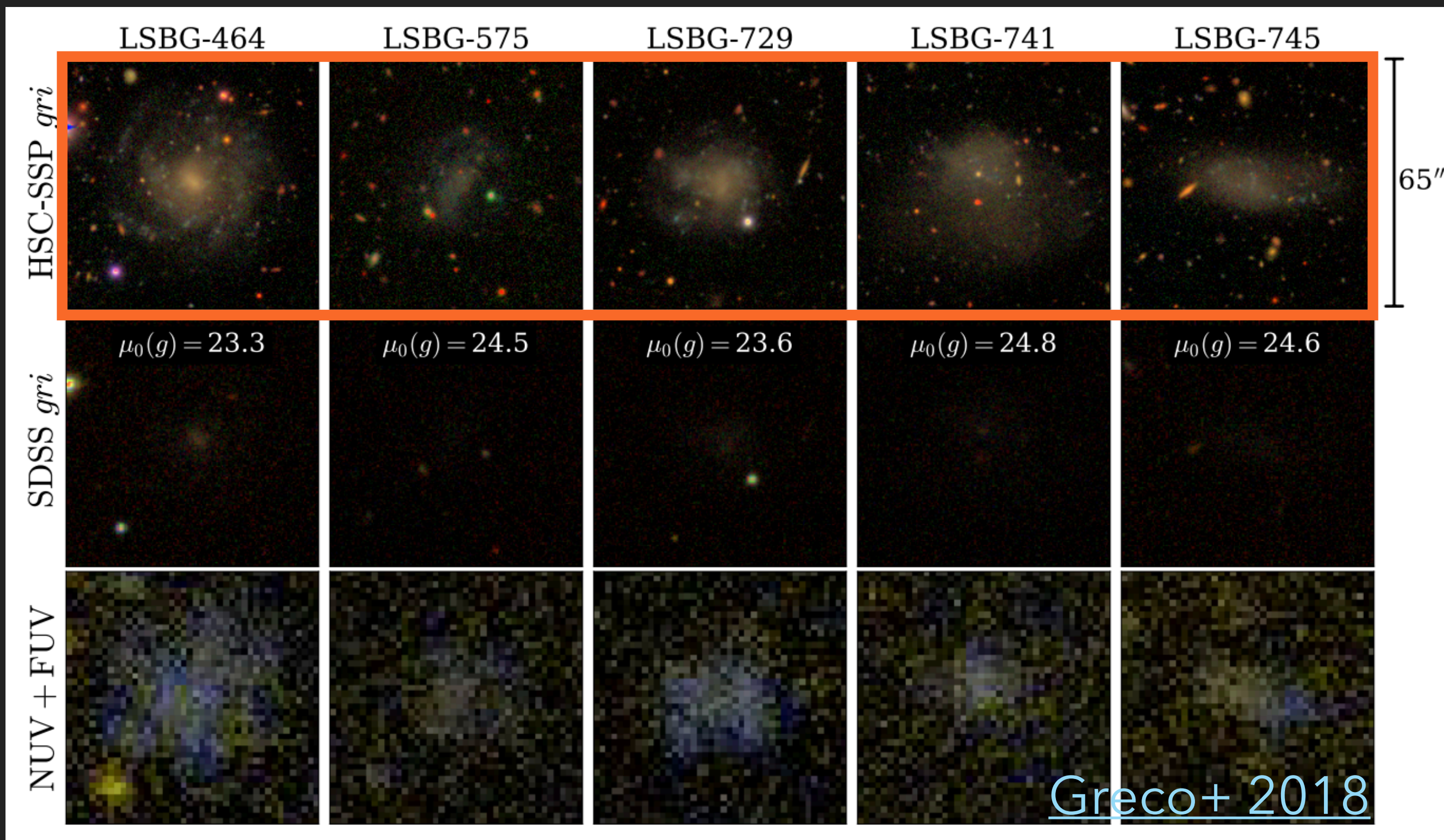




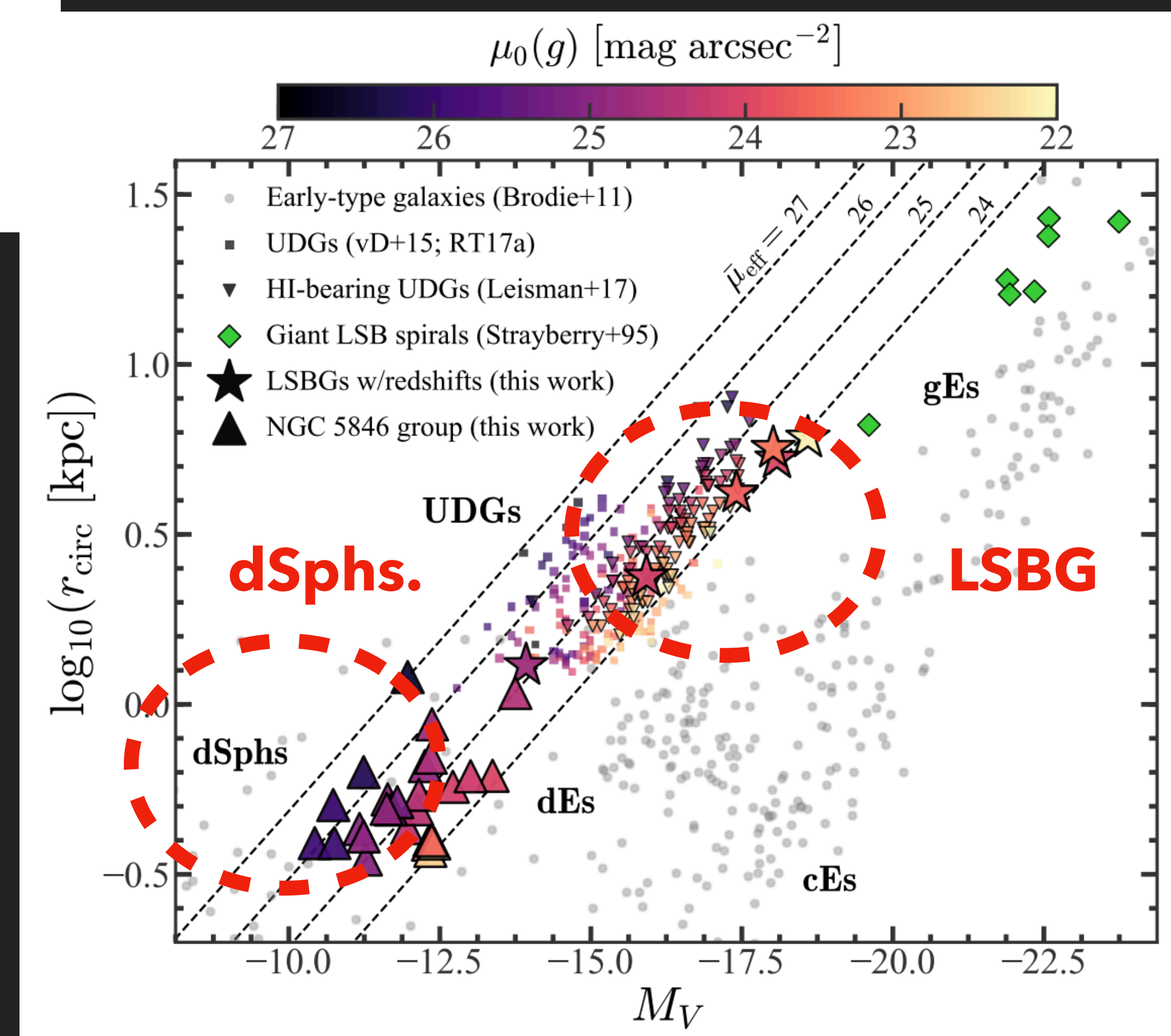
binary classification of CDM and WDM



COLLECTING GAMMA-RAY PHOTON AT LSBG POSITIONS



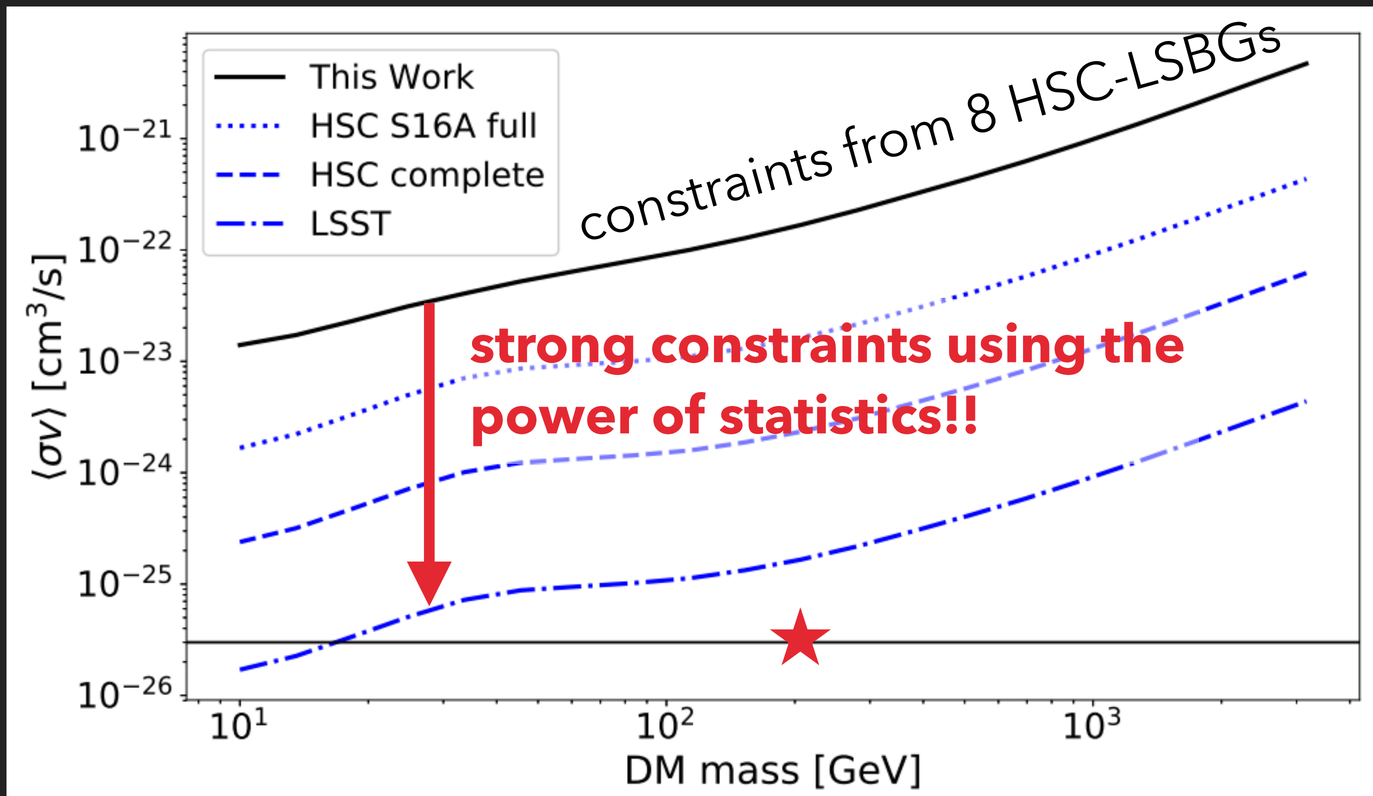
- 10-100 times more massive than dSphs!!
- r ~ 20 Mpc/h (a bit distant…)
- should be more at closer distances.
- Lots of LSBG expected, all sky!



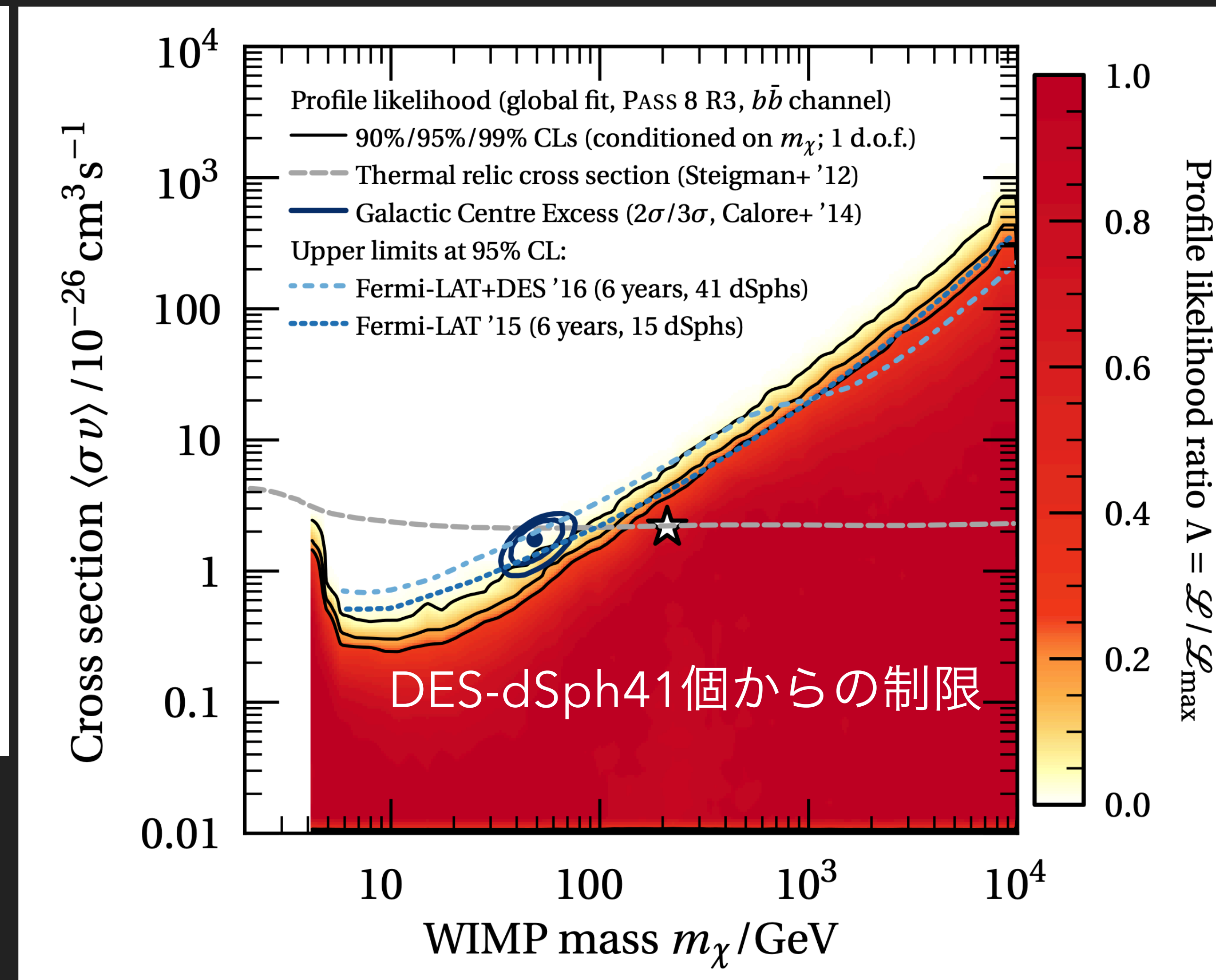
- Low Surface Brightness Galaxy
- Large number of LSBGs are newly found by HSC thanks to their superb sensitivities
- ~800 LSBGs for HSC Y1 (only 8 LSBGs are distance known)
- ~20,000 LSBGs for DES Y3
- More in Future (e.g. LSST)

WHY LSBG?

c.f. Hoof et al. 2020



Hashimoto, AJN, Takada and Macias 2021



- The constraints gets stringent prop. to **N stacked**
  ☝ The number of objects are huge compared to dSph.
- We do not need to know the exact distance but **overall distribution is sufficient**
  ☝ Do not need to spectroscopic follow-up observation for faint galaxies

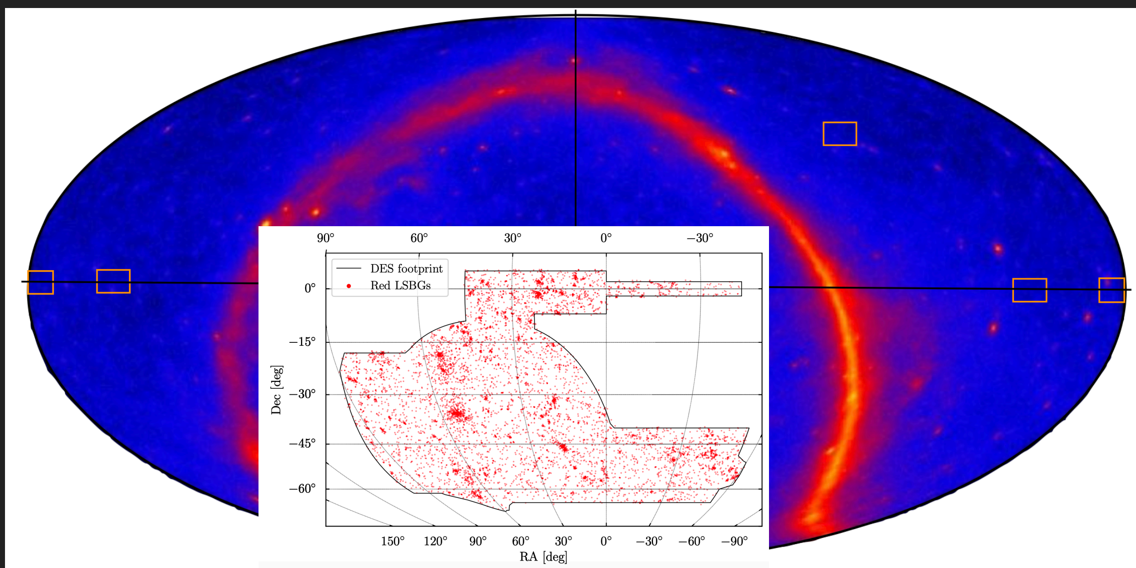
Hashimoto

Macias

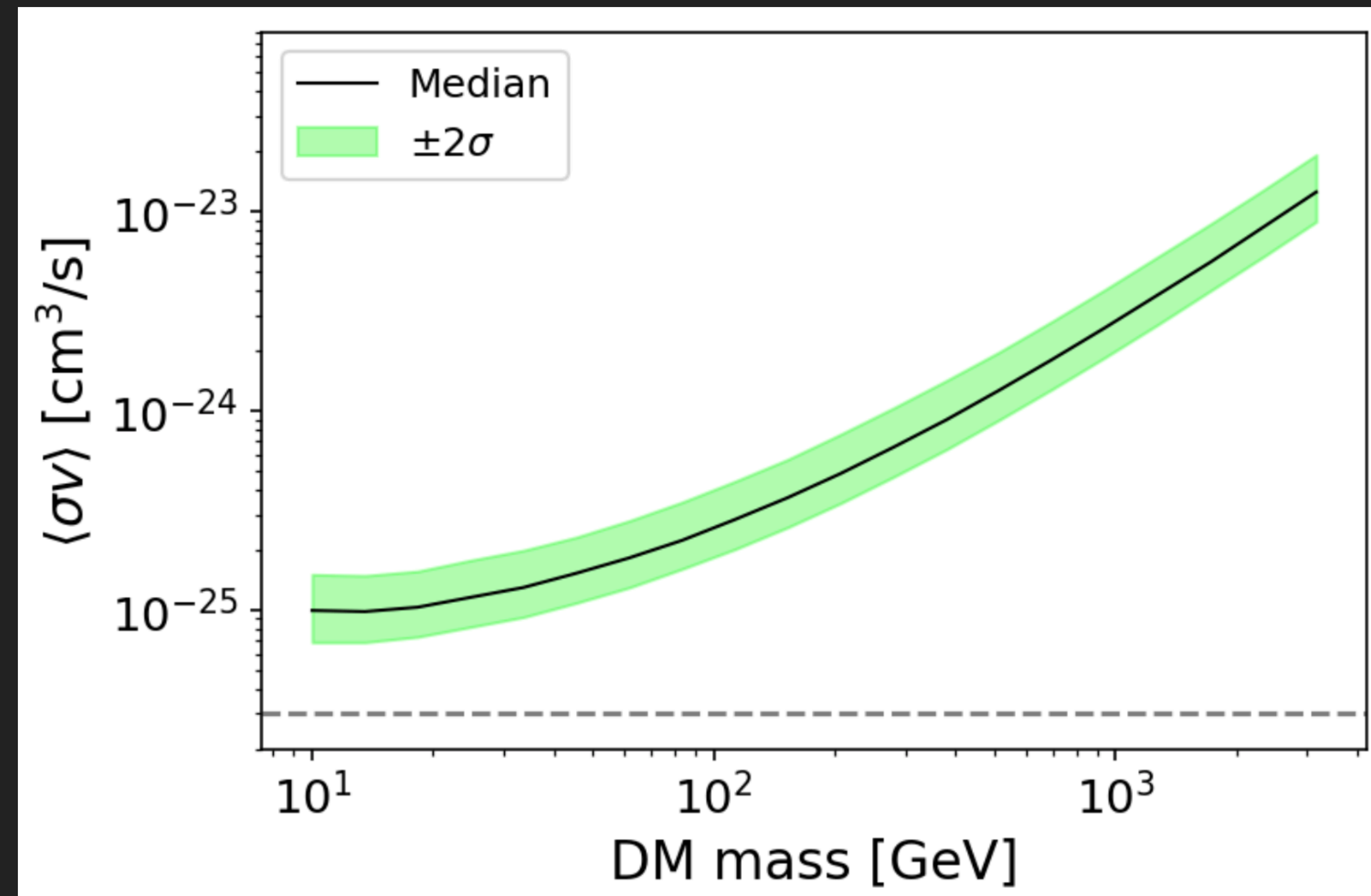
$$\frac{d\Phi_\gamma}{dE_\gamma} = \boxed{J} \times \frac{\langle\sigma v\rangle}{8\pi m_\chi^2}\sum_i B_i \frac{dN_i}{dE'_\gamma}$$

J-factor

SUMMARY



Hashimoto, AJN, and Takada 2022



- We obtained a constraints from DES Y3 and Fermi 12Y data set
- The constraints are still weaker than current dSph, but will get more stringent constraint in the era of LSST or Roman.
- Papers submitted,

  Hashimoto AJN+ 2021 [2109.08832]

  Hashimoto AJN+ 2022 [2202.01400]

- one paper is in preparation (Murakami et al.)

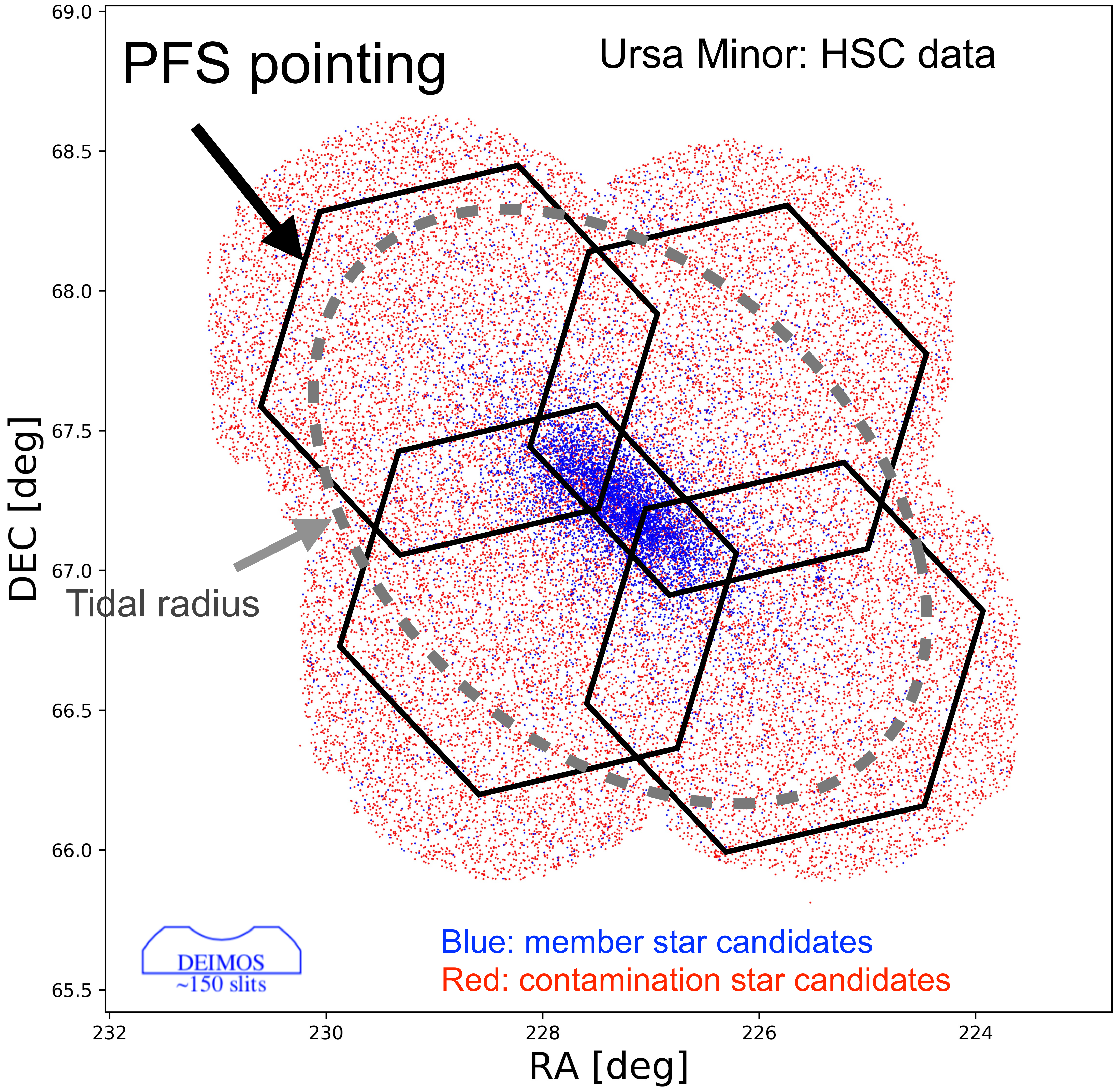
F06

Comprehensive study of dynamical structures in the Galactic dwarf galaxies by Subaru and shedding light on the nature of dark matter

公募研究「すばる望遠鏡による銀河系矮小銀河の網羅的動力学研究とダークマターの正体解明」

Kohei Hayashi (NIT, Ichinoseki College)

Subaru-PFS is coming soon.



Current
$N_{\mathrm{spec.}} \sim 300$ ⇨ PFS
$N_{\mathrm{spec.}} \sim 5000$

Wide & deep PFS survey:

Huge number of stellar kinematics out to the outskirts of the Galactic dSphs.

- Combining a huge data volume and dynamical analysis can place severe constraint on their DM distributions.
- There are many kinds of dynamical analysis models.
- **No one inspects systematic uncertainties among the models on the inferred DM distributions.**

Main goals:

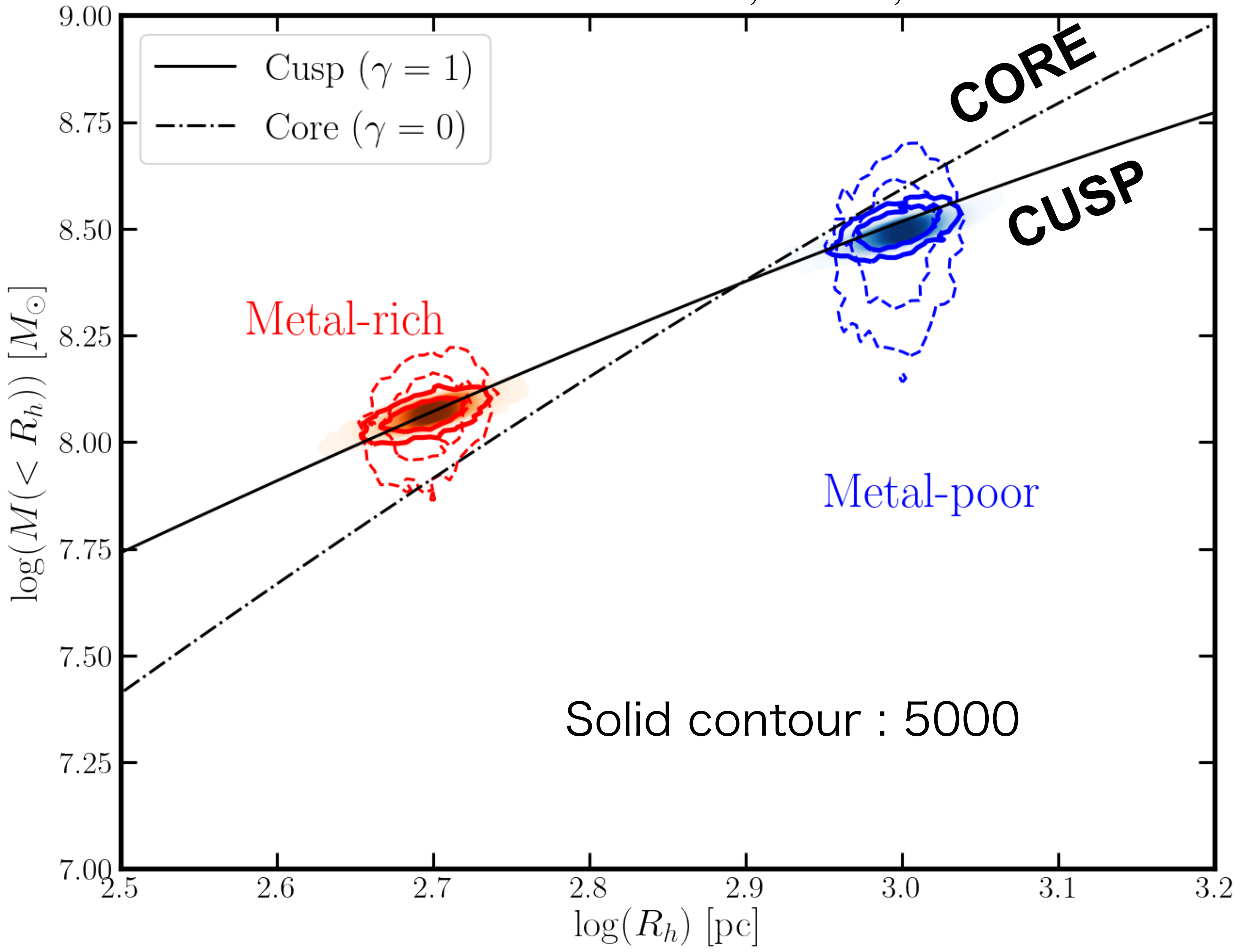
1. Develop more than one dynamical modelings
2. Compare quantitatively the estimated DM density profiles from developed independent methods.

KH and PFS-GA science WG

Current status

- **Mass slope method (Walker & Penarrubia 2011)**

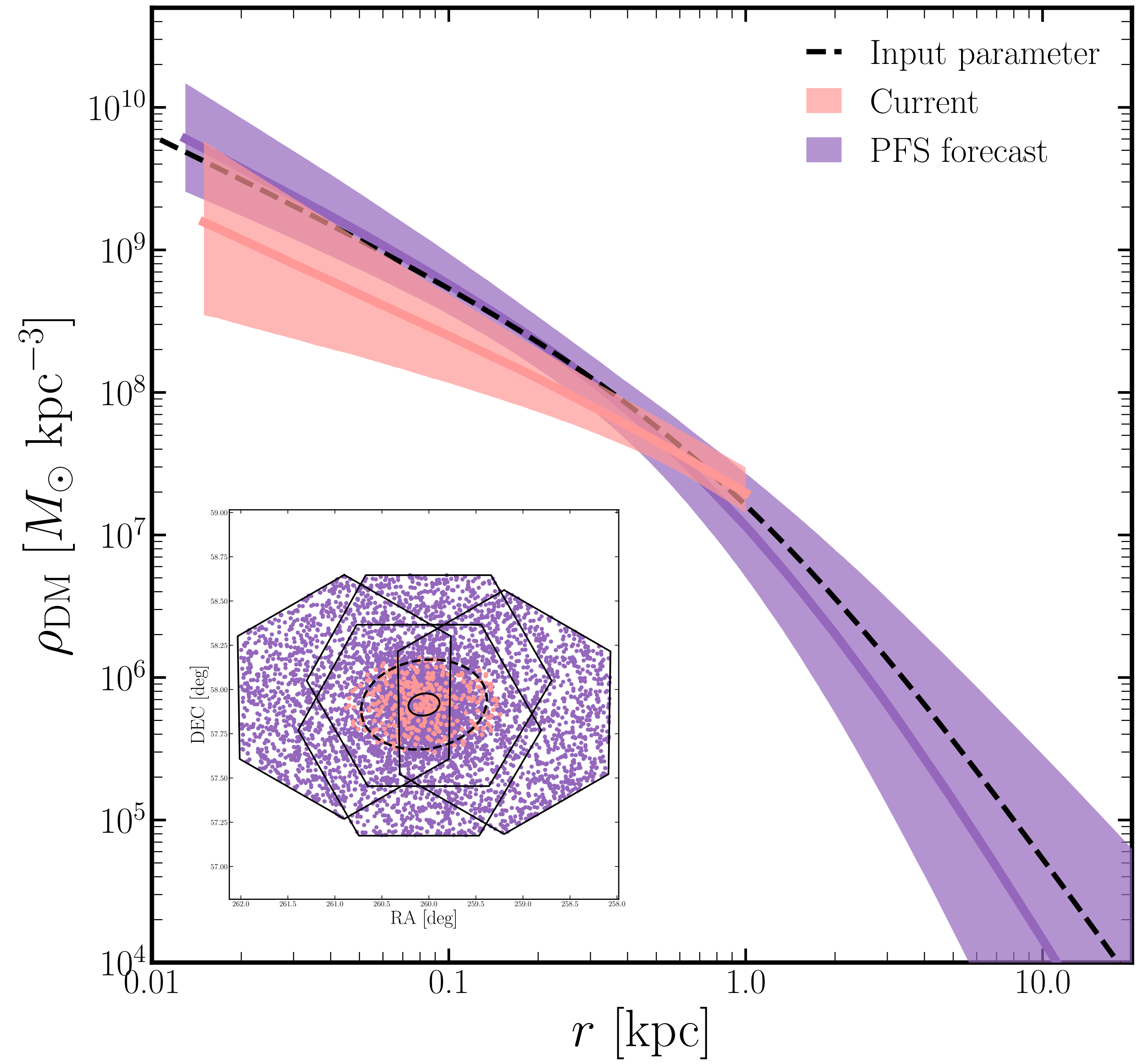
$$\Gamma \equiv \frac{\Delta \log M}{\Delta \log r} = \frac{\log[M(r_{\rm h,MP})/M(r_{\rm h,MR})]}{\log[r_{\rm h,MP}/r_{\rm h,MR}]}$$



Mass slope with large data can distinguish between cusp and core.

- **2nd-order Jeans eq. (l-o-s velocity dispersion)**

Estimated DM profile from Jeans eq.



Jeans analysis with large data can recover an input DM density profile from the center to outer parts.

<u>**Future plan**</u>

- Develop the other dynamical methods:

Higher-order Jeans analysis (skewness, kurtosis), Orbit-superposition method (Schwarzschild method), Distribution functions.

- PFS mock analysis

Dark matter halo properties of the Galactic dwarfs

Hayashi, Hirai, Chiba and Ishiyama (in prep.)

- Axi. Jeans analysis for 8 classicals, 25 UFDs, and 2 ultra-diffuse gals in the MW
- Variety of DM inner density slopes (Fig. 1)
- $\rho_{\rm DM}(150{\rm pc})$ vs . $r_{\rm peri}$ (Fig. 2)

✳ Tucana, Antlia 2, and Crater 2 galaxies deviate from the predictions from ΛCDM simulations significantly.

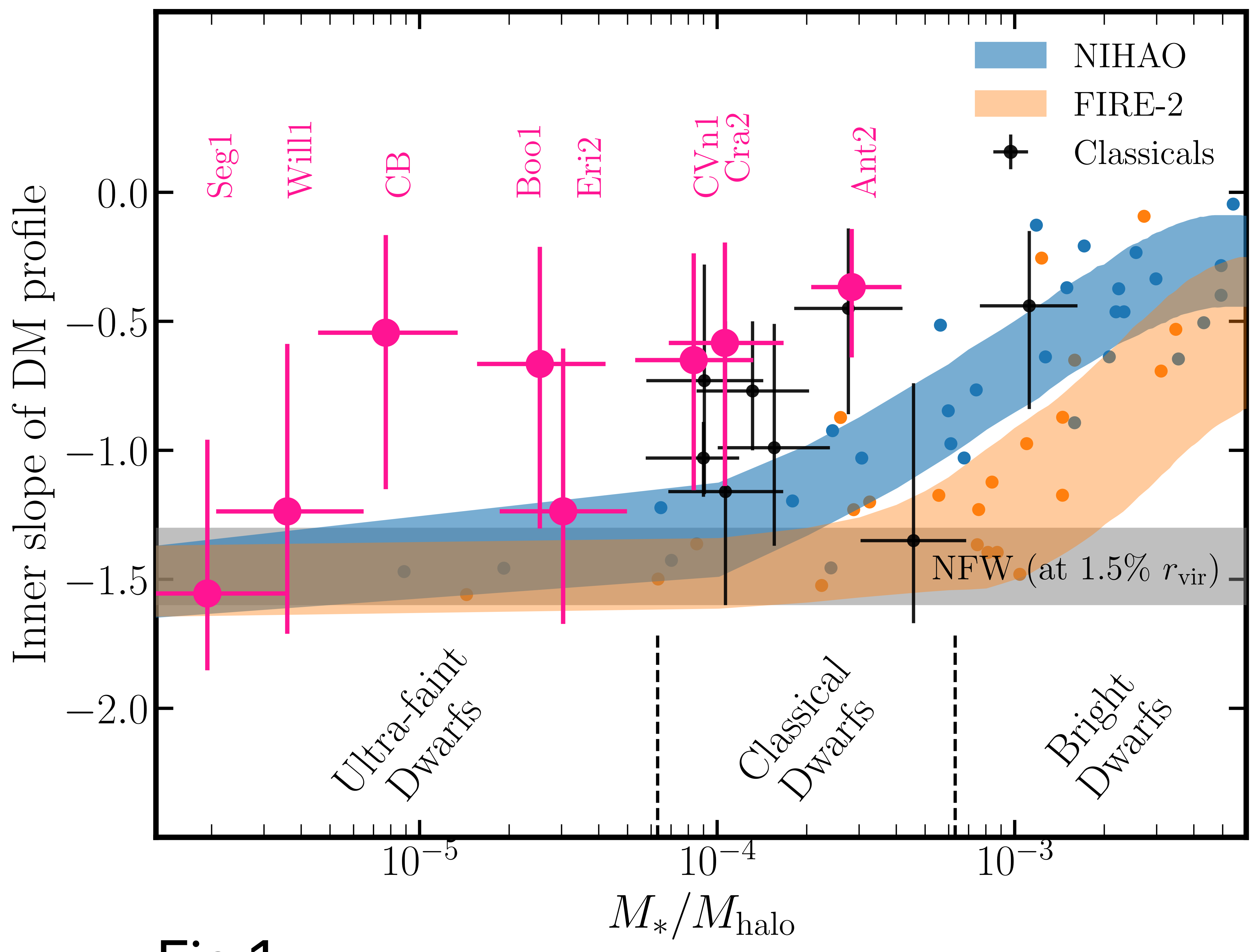


Fig.1

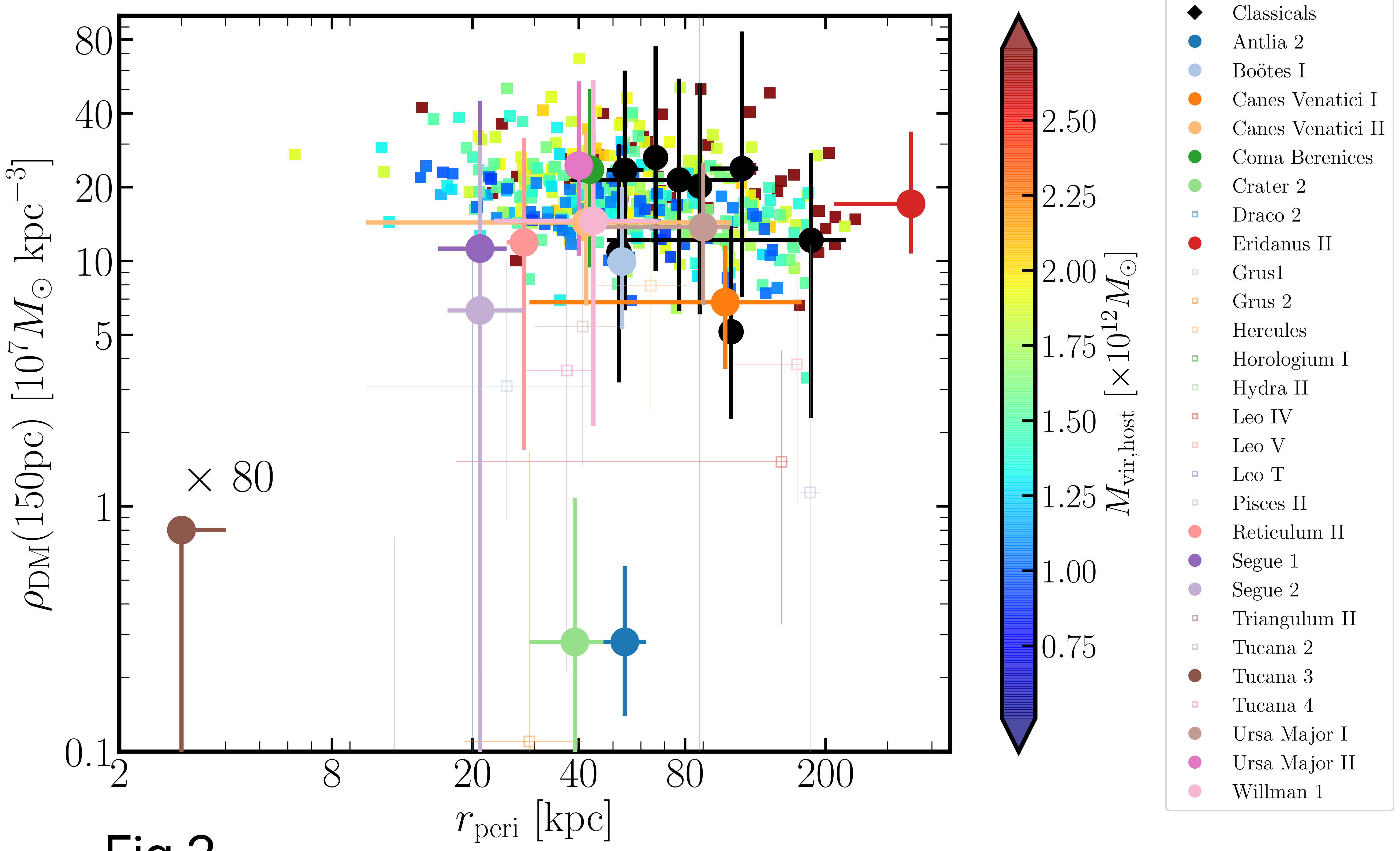


Fig.2

F07

Toward search for light scalar field dark matter by interferometers

Teruaki Suyama

Tokyo Institute of Technology

Collaborators: Soichiro Morisaki (Univ. of Wiskonsin)
Kouki Fukusumi (Tokyo Tech)

DM may be a light scalar field ϕ weakly interacting with us.

$$\mathcal{L}_{\phi-\mathrm{SM}} = \kappa\phi\left[\frac{d_e}{4e^2}F_{\mu\nu}F^{\mu\nu} - \frac{d_g\beta_3}{2g_3}G^A_{\mu\nu}G^{A\mu\nu} - \sum_{i=e,u,d}(d_{m_i} + \gamma_{m_i}d_g)m_i\bar{\psi}_i\psi_i\right]$$

ϕ behaves as a classical stochastic wave with $\omega \approx m$.

Any bodies receive a periodically changing scalar force $\phi(t)$.

$$\frac{d^2\boldsymbol{x}}{dt^2} = -\kappa d_g^* \boldsymbol{\nabla}\phi$$

Signals in the GW interferometers

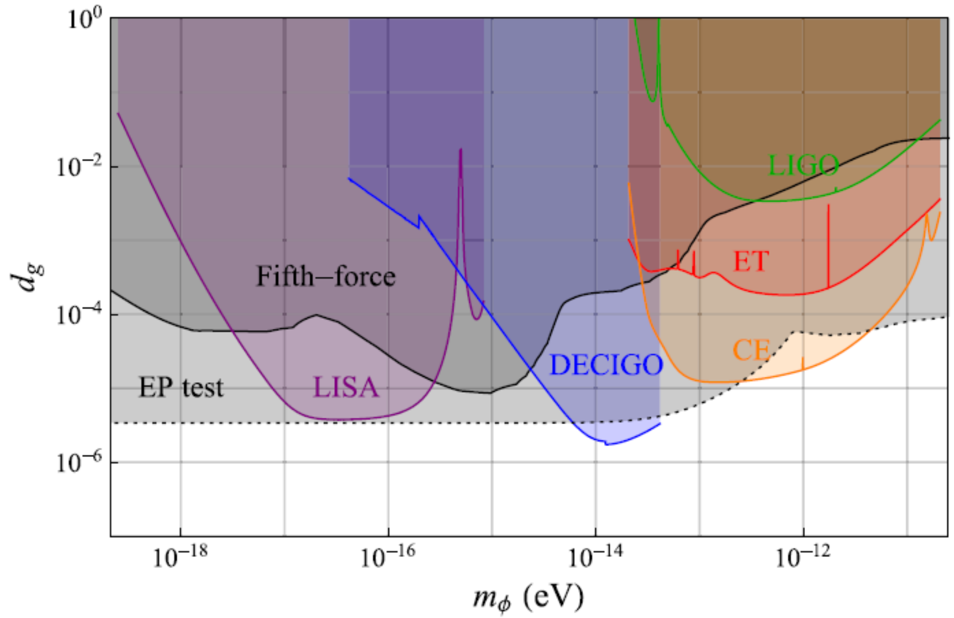
(m, d_g^*) are the model parameters.

PHYSICAL REVIEW D **100,** 123512 (2019)

Detectability of ultralight scalar field dark matter with gravitational-wave detectors

Soichiro Morisaki[1,2] and Teruaki Suyama[3]
[1]*Research Center for the Early Universe (RESCEU), Graduate School of Science, The University of Tokyo, Tokyo 113-0033, Japan*
[2]*Department of Physics, Graduate School of Science, The University of Tokyo, Tokyo 113-0033, Japan*
[3]*Department of Physics, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8551, Japan*

(Received 4 March 2019; revised manuscript received 25 September 2019; published 10 December 2019)



Since data exists, it is natural to formulate a search method (cross correlation) and apply it to real data.

Formulation

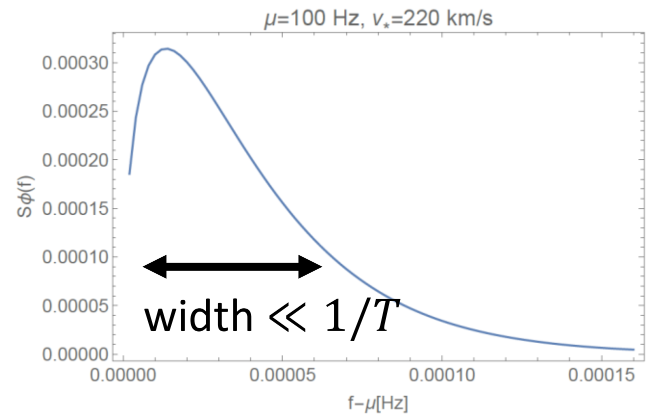
Stochastic scalar wave

$$\phi(t, \boldsymbol{x}) = \int d\hat{\Omega} \int_{-\infty}^{\infty} df \ e^{-2\pi i f(t-\eta\hat{\Omega}\cdot\boldsymbol{x})} u(f, \hat{\Omega})$$

$$\langle u^*(f, \hat{\Omega}) u(f', \hat{\Omega}') \rangle = \delta(f-f') \frac{1}{4\pi} \delta(\hat{\Omega}, \hat{\Omega}') \times \frac{1}{2} S_\phi(f)$$

Spectral density of ϕ

$$S_\phi(f) = \frac{4\rho_{\rm loc}}{\pi^{5/2}\mu^3 v_*^3} \eta \exp\left(-\frac{f^2\eta^2}{v_*^2\mu^2}\right)$$



Signal of the interferometer (valid for T → ∞)

$$\tilde{s}(f) = \int d\hat{\Omega} F(\hat{\Omega}, f) e^{2\pi i f \eta \hat{\Omega}\cdot\boldsymbol{x}} u(f, \hat{\Omega})$$

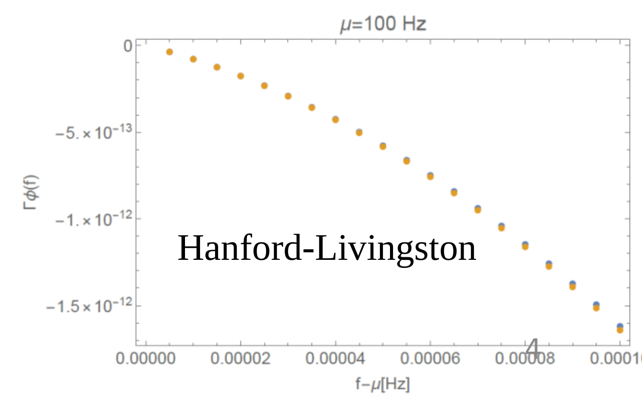
$$F(\hat{\Omega}, f) = -\frac{\kappa d_g^*}{\pi i L f}\left(\hat{m}\cdot\hat{\Omega} - \hat{n}\cdot\hat{\Omega}\right)\eta \sin^2(\pi f L) - \kappa d_g^* \left((\hat{m}\cdot\hat{\Omega})^2 - (\hat{n}\cdot\hat{\Omega})^2\right)\eta^2$$

Cross-correlation

$$\langle \tilde{s}_1(f) \tilde{s}_2(f) \rangle = \frac{T}{2} \Gamma_\phi(f) S_\phi(f)$$

Overlap function

$$\Gamma_\phi(f) \equiv \int \frac{d\hat{\Omega}}{4\pi} F_1^*(\hat{\Omega}, f) F_2(\hat{\Omega}, f) e^{2\pi i f \eta \hat{\Omega}\cdot\boldsymbol{\Delta x}}$$



Formulation

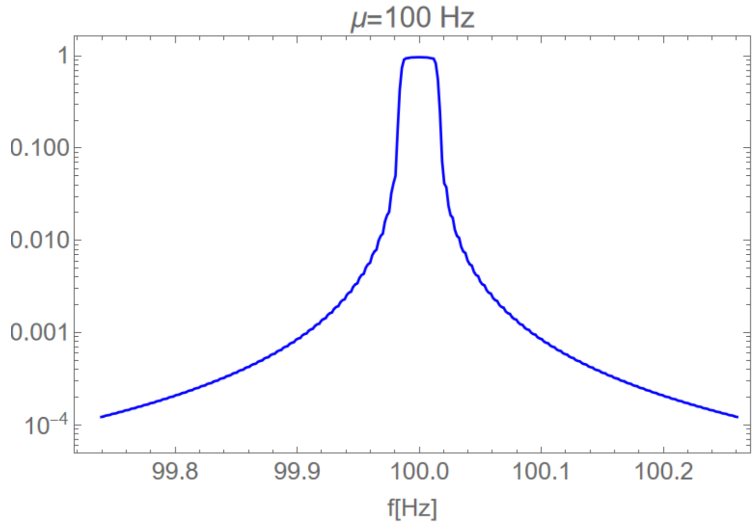
Since width of $S_\phi \ll 1/T$, fine spike is smeared out in real data.

$$\langle \tilde{S}^*_{1,\mathrm{obs}}(f)\tilde{S}_{2,\mathrm{obs}}(f)\rangle \approx \frac{1}{2}\left[\frac{\sin(\pi(\mu-f)T)}{\pi(\mu-f)}\right]^2 \int_\mu^\infty \Gamma_\phi(f')S_\phi(f')df'$$

$$\int_\mu^\infty \Gamma_\phi(f')S_\phi(f')df' \approx \frac{3\rho_{\mathrm{loc}}v_*^2}{4\pi^2\mu^2}(2a_1\mu^2L^2 + 5a_2v_*^2)$$

Public data (cross-correlation statistic $\hat{C}(f)$) by LVK Collaborations

$$\int_{f-\frac{\Delta f}{2}}^{f+\frac{\Delta f}{2}} \tilde{S}^*_{1,\mathrm{obs}}(f')\tilde{S}_{2,\mathrm{obs}}(f')df'$$



If the data contains DM signal, we should observe this shape of signal in the cross-correlation data.

Next stage: Search for this signal in the public data

F08

Search for TeV-Range Dark Matter with Electron and Positron Cosmic Rays

Holger Motz
Waseda University
Faculty of Science and Engineering
Global Center for Science and Engineering

- **Product:** Limits on DM annihilation and decay from a combined analysis of the latest all-electron spectrum measured by CALET [S. Torii, Y. Akaike et al. POS ICRC 2021 (105)] and the positron-only spectrum from AMS-02 [M. Aguilar et al. Phys. Rev. Lett. 122, 041102]

- **Basic Concept:** Astrophysical base model which fits the data well → add flux from DM calculated with DRAGON and increase scale factor → limit on annihilation rate or lifetime when χ^2 exceeds the 95%CL threshold

- **Goal:** Extend limits to heavy DM in the TeV-mass range (candidates beyond WIMP model) making use of CALET's TeV-region electron spectrum measurement

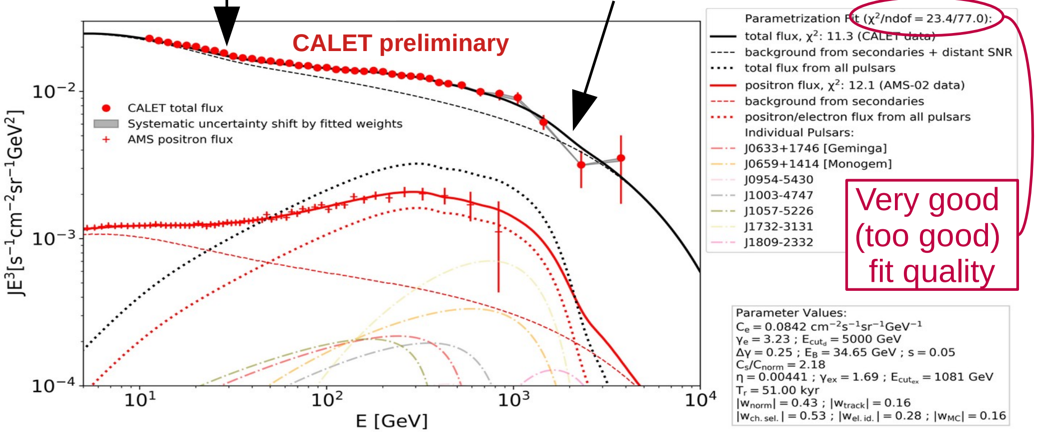
Currently used astrophysical base model:
Primary electron spectrum with low-energy spectral break and exponential cut-off, secondary electrons, secondary positrons, extra pulsar source for positron excess

$$\Phi_{ele} = C_e E^{-(\gamma_e - \Delta\gamma_e)} \left(1 + \left(\frac{E}{E_B}\right)^{\frac{\Delta\gamma_e}{s}}\right)^{s} e^{-\left(\frac{E}{E_{cut_d}}\right)} + C_s \Phi_{s(e^-)} + \Phi_{ex}$$

$$\Phi_{pos} = C_s \Phi_{s(e^+)} + \Phi_{ex} \quad ; \quad \Phi_{tot} = \Phi_{ele} + \Phi_{pos}$$

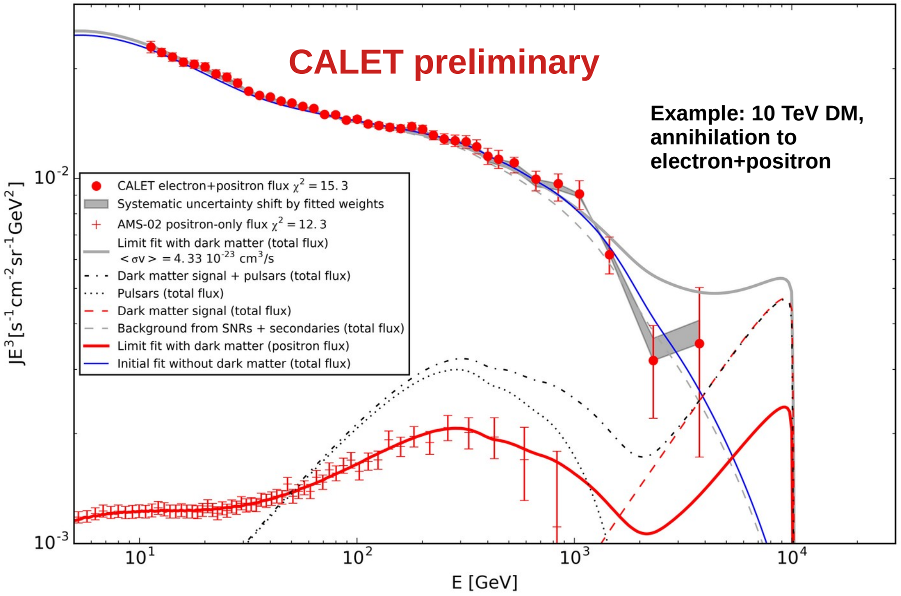
Smooth break in the **primary electron spectrum**

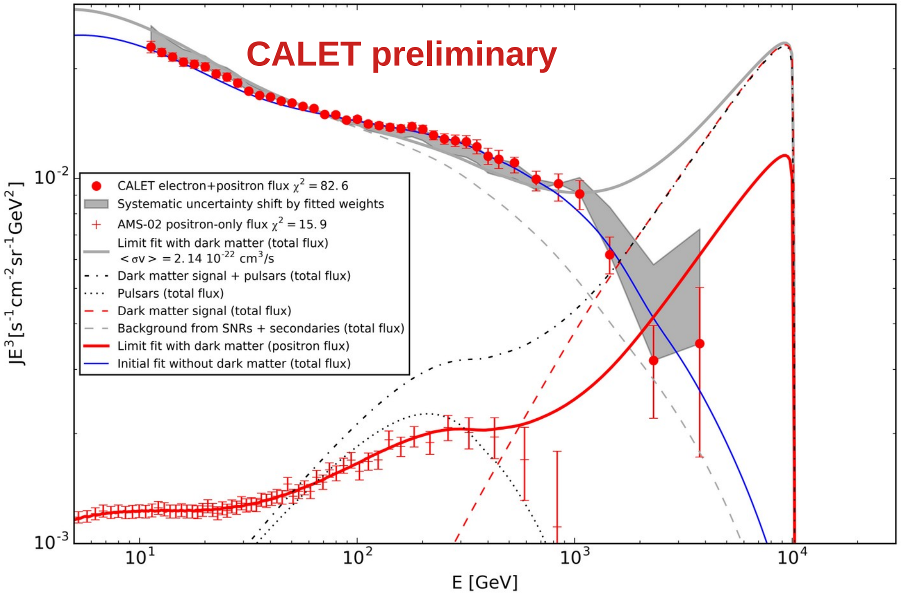
Exponential cut-off of **primary electron spectrum** from energy loss, best fit for **$E_{cut(d)}$ = 5 TeV** but not well constrained → consider values of **$E_{cut(d)}$ in [1 TeV, 100 TeV]**



Pulsar position, age and energy from ATNF catalog. Release time, index, efficiency, cut-off are free parameters but the same for all pulsars

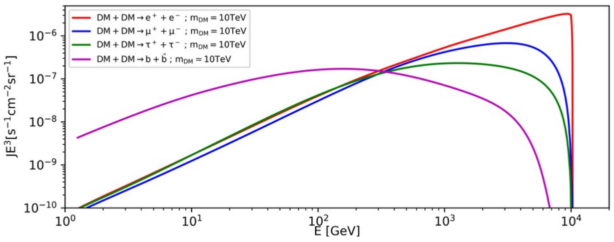
Limit Calculation





Relative Limit: χ^2 increases by 3.841 compared to χ^2 of the base model, thus the addition of DM is disfavored at 95% CL (better but not conservative since base model is over-fitted - assumes the base model is true, which is not certain)

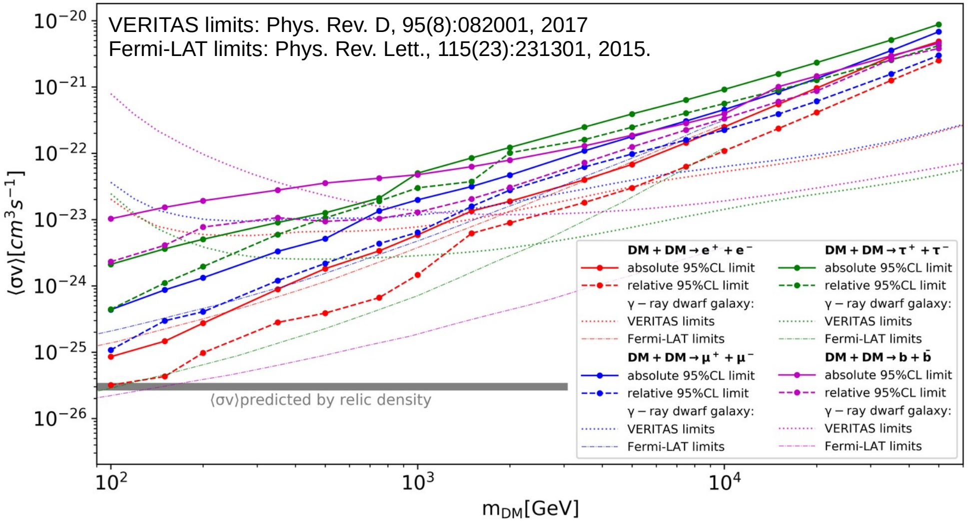
Absolute Limit: χ^2 exceeds the 95% CL threshold for the fit's number of degrees of freedom, thus the whole model including the DM flux is excluded



- Flux of electrons and positrons per annihilation or decay from decay of primary annihilation products calculated with PYTHIA
- Flux at Earth calculated with DRAGON (using propagation parameters tuned to measured nuclei spectra up to Oxygen), assuming 0.3 GeV/cm^3 local DM density and NFW halo.

← **Flux for annihilation channels, $<\sigma v> = 3\times10^{-26}$ cm^3/s**

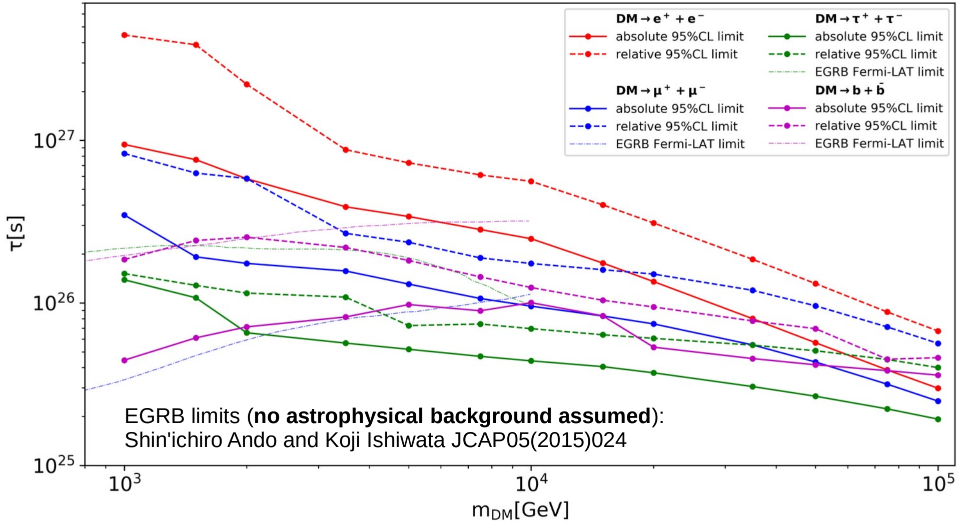
Limit Results

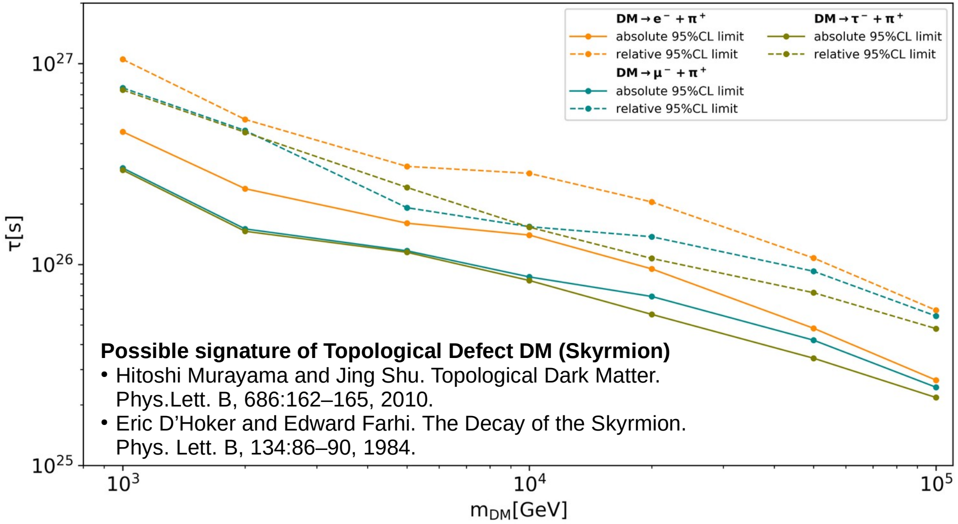


Highest limit from scan over E_{cut} in [1,2,5,10,50,100 TeV] used for each mass

Annihilation	Decay	Decay (Skyrmion)
DM+DM → e^++e^-	DM → e^++e^-	DM → π^+ + e^-
DM+DM → μ^++μ^-	DM → μ^++μ^-	DM → π^+ + μ^-
DM+DM → τ^++τ^-	DM → e^++e^-	DM → π^+ + τ^-
DM+DM → b+$\bar{b}$	DM → b+$\bar{b}$	

Annihilation: Cross-section limits up to 50 TeV DM mass
Decay: Lifetime limits up to 100 TeV DM mass
(not a fixed boundary, but influence of propagation increases since relying on the low-energy tail of the flux from DM, also calculation of annihilation/decay spectra with PYTHIA maybe not including some effects at such high energy)

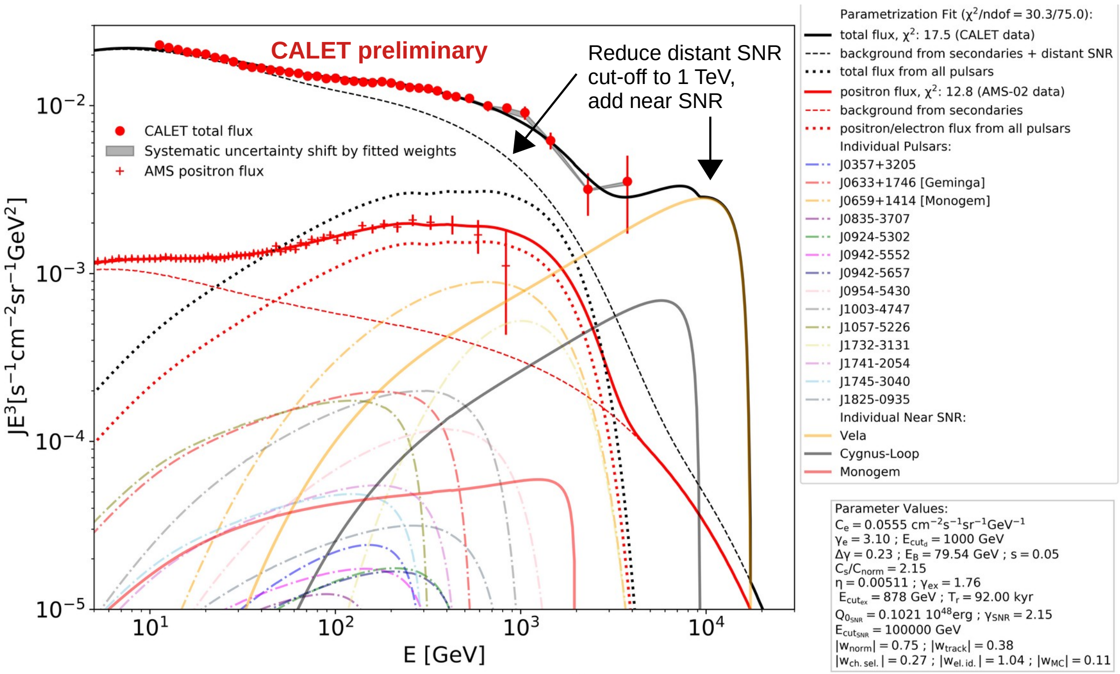




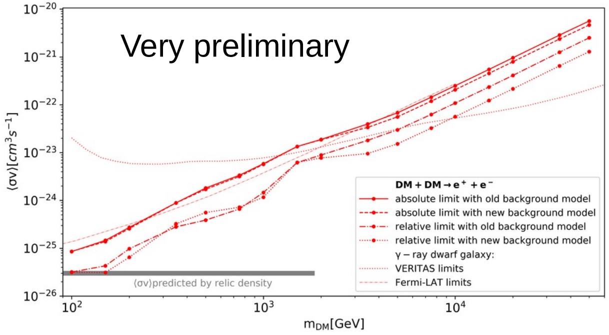
Improvements to Astrophysical Bkg. Model

- **Completed:**
  - In TeV region few nearby SNR expected to dominate the spectrum → known nearby young SNRs (Vela, Cygnus Loop, Monogem) added as individual sources (same calculation method as pulsars)
  - Klein-Nishina Effect becomes very important at TeV energy range → included in analytic propagation calculation for astrophysical sources

- **Plans:**
  - Replace phenomenological broken power-law with cut-off model for the primary electron spectrum with randomly sampled SNR sources choosing samples fitting the data within $\chi2/\mathrm{ndof} < 1$
    → take worst limit from many samples
    → considering many background scenarios, relative limit could be considered sufficiently robust
  - Study more propagation conditions (magnetic field strength not well constrained by nuclei spectra)



Limits with the improved background model are consistent with those from the old model (relative limits show some difference as expected)



Conclusions & Outlook

- Direct measurements of electron and positron cosmic rays can be a probe for annihilation and decay of heavy DM well into the TeV mass range.
- With the current electron+positron spectrum data from CALET up to 4.8 TeV, together with positron-only AMS-02 data, limits on decaying DM lifetime up to 100 TeV DM mass (annihilation: 50 TeV) have been obtained.
- Limited propagation distance of high-energy electrons → target region is ~1kpc local region of the DM halo → complementary to γ-ray observation of dwarf galaxies or the EGRB due to different sources of systematic uncertainty
- Relative limits are better than absolute limits but not reliable since base-model over-fitted → nearby SNR sources and random variation of the background by distribution of individual SNR sources should be taken into account to use them
- Limits for further annihilation/decay channels could be calculated → suggestions/collaboration on specific dark matter candidates highly welcome

The author gratefully acknowledges the support of the CALET collaboration team in making the preliminary results published at ICRC2021 available for use in this work. This work is supported by JSPS KAKENHI Grants No. JP21H05463 and No. JP21K03604.

F09

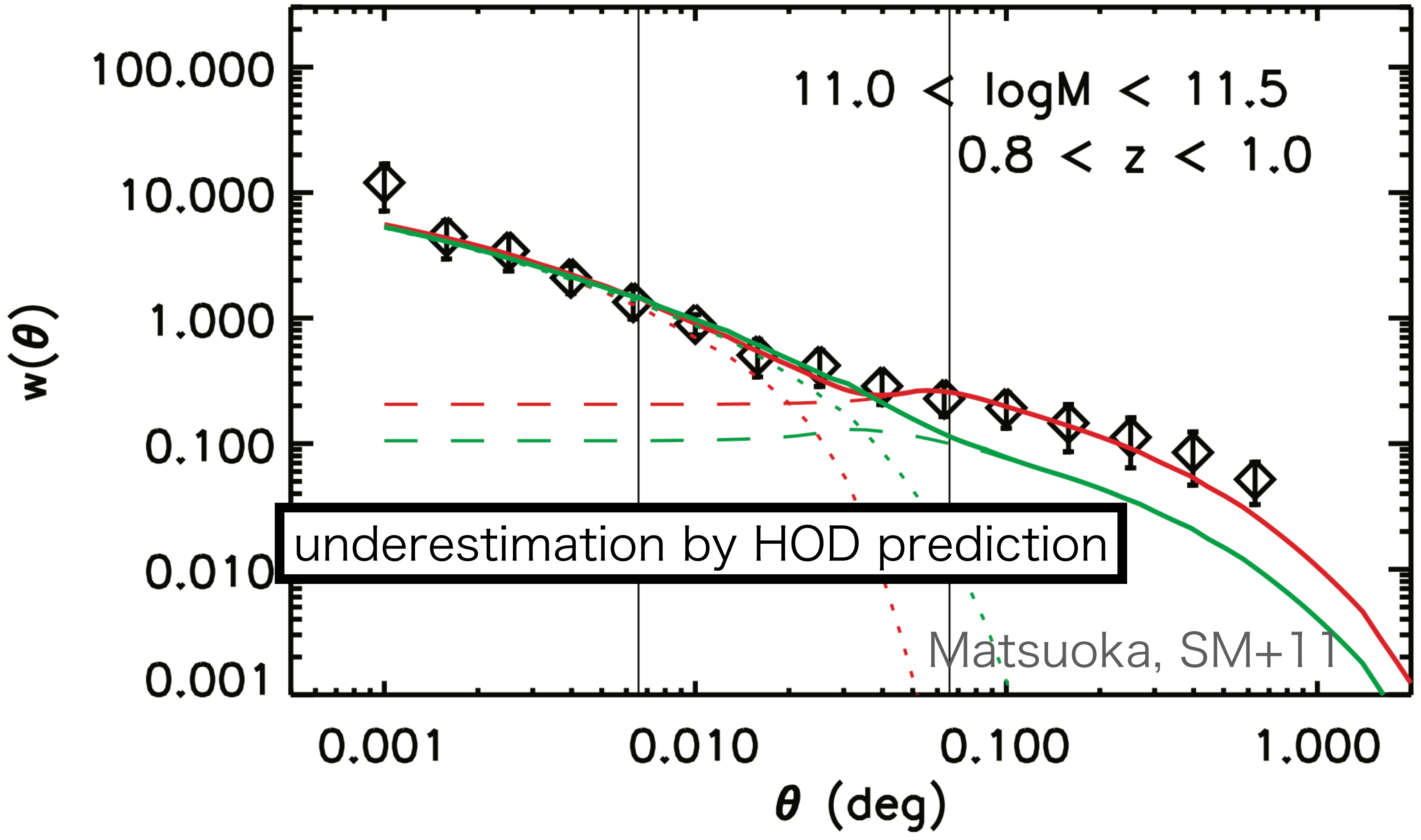
Validation of CDM cosmology for large-scale structure formation by considering cosmic variance

Shogo Masaki (National Institute of Technology, Suzuka College)

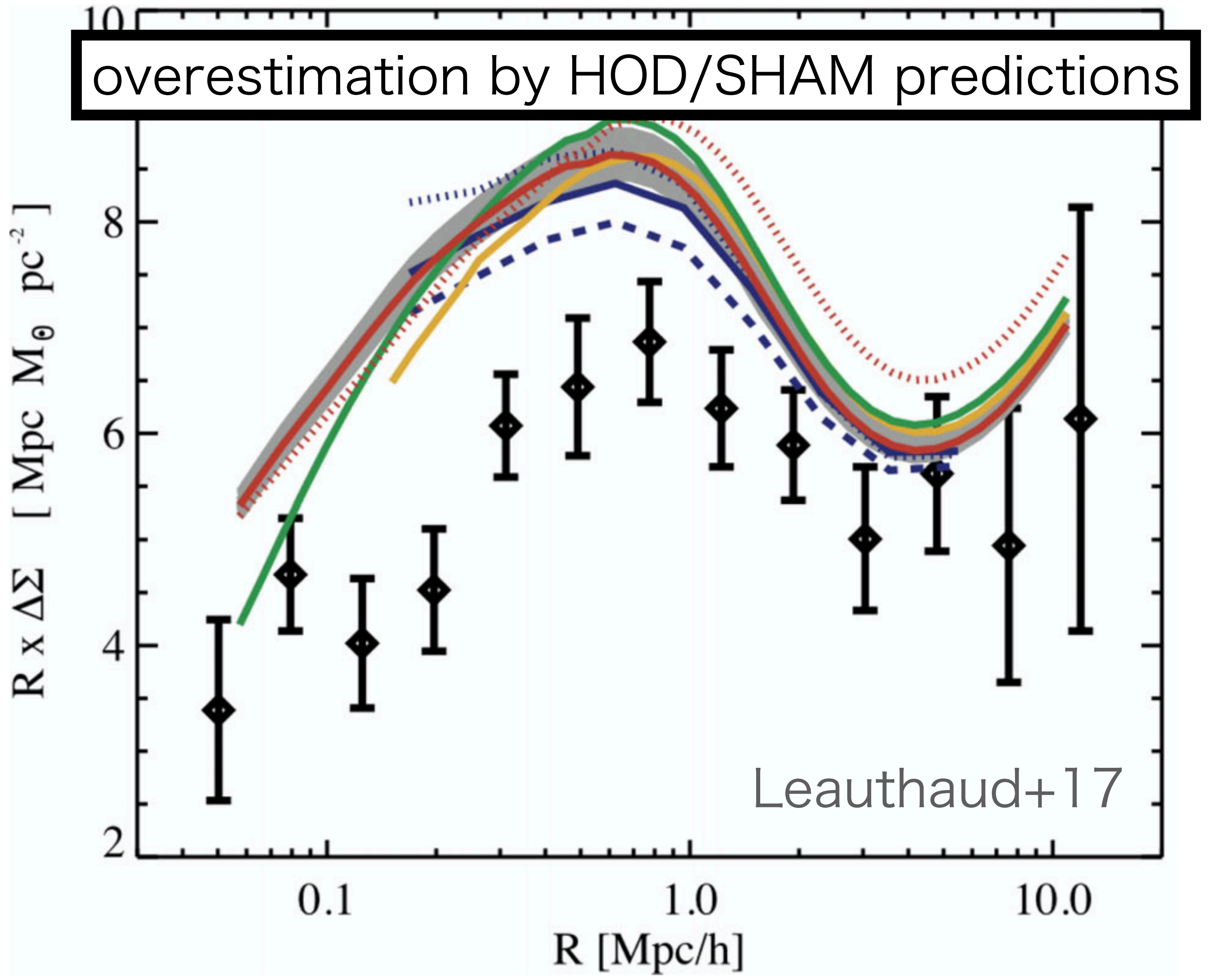
Background of this project

- The CDM model works well for large-scale structure formation while the problems on sub-galactic scales (missing satellite, core-cusp…).
- However, some observations on large scales cannot be reproduced by the standard modeling.

Angular correlation of massive galaxies



Massive galaxy-mass cross correlation

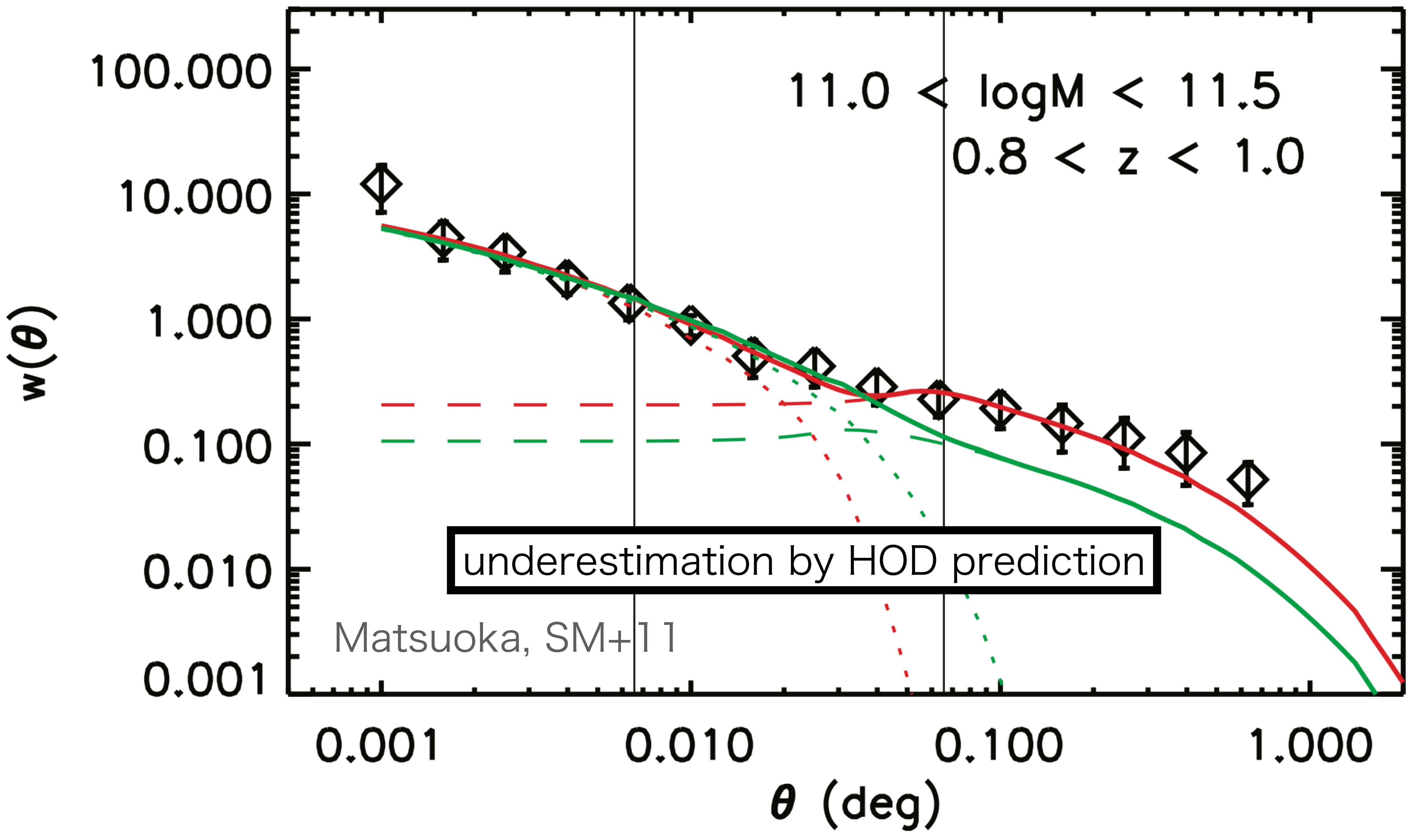


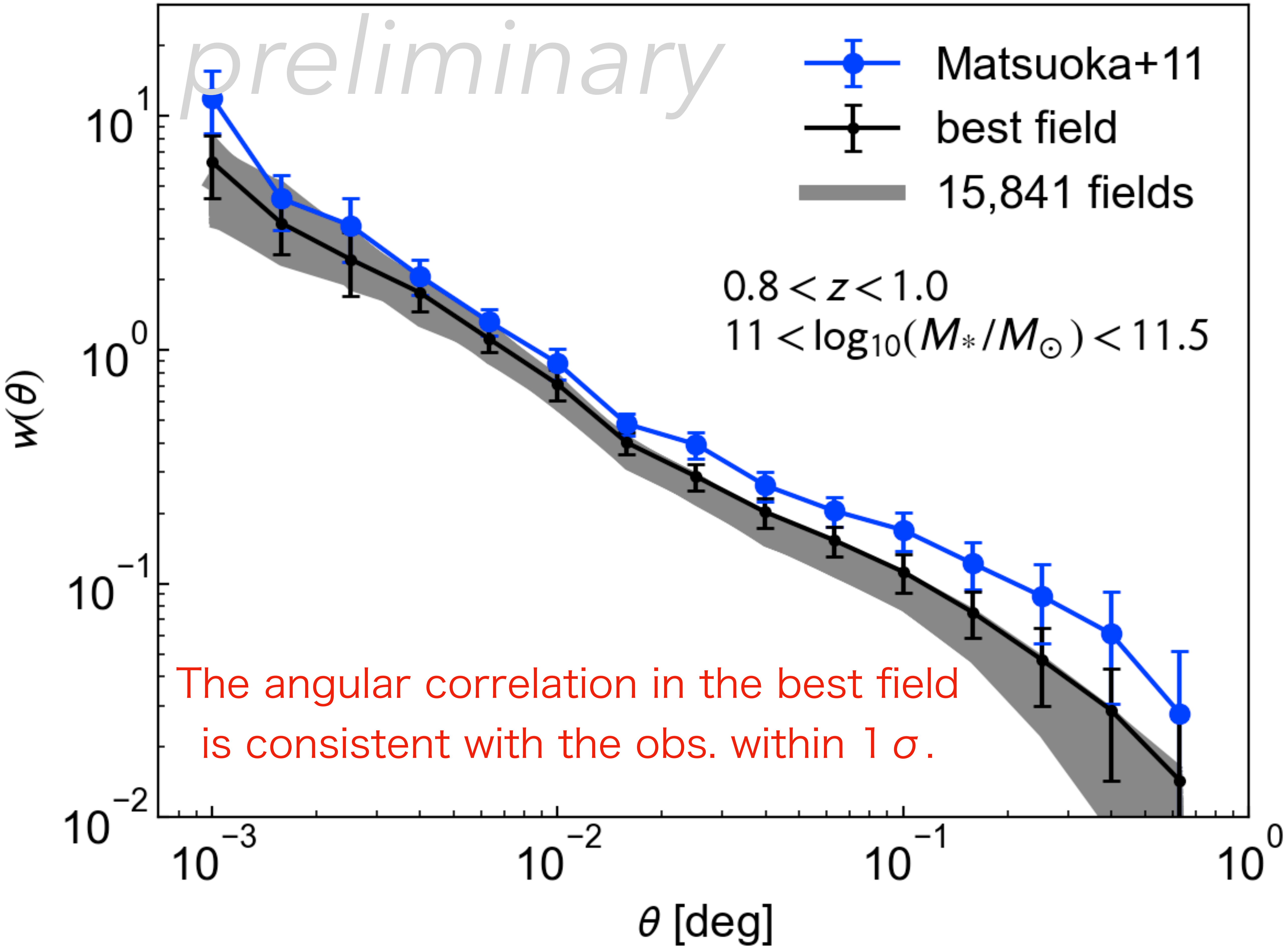
Aims

- **This project clarifies “what’s happening?” to validate the CDM model for large-scale structure formation.**
- Especially by considering the cosmic variance.
  - Since massive galaxies are rare objects, there could be substantial field-to-field scatters on correlation measurements.
  - To do so, we populate dark halos with galaxies by subhalo abundance matching (SHAM) using the Uchuu simulation (2 Gpc/h box, Mpart = 3e8 Msun/h) by Ishiyama+21.

Status report: Revisiting massive galaxy clustering

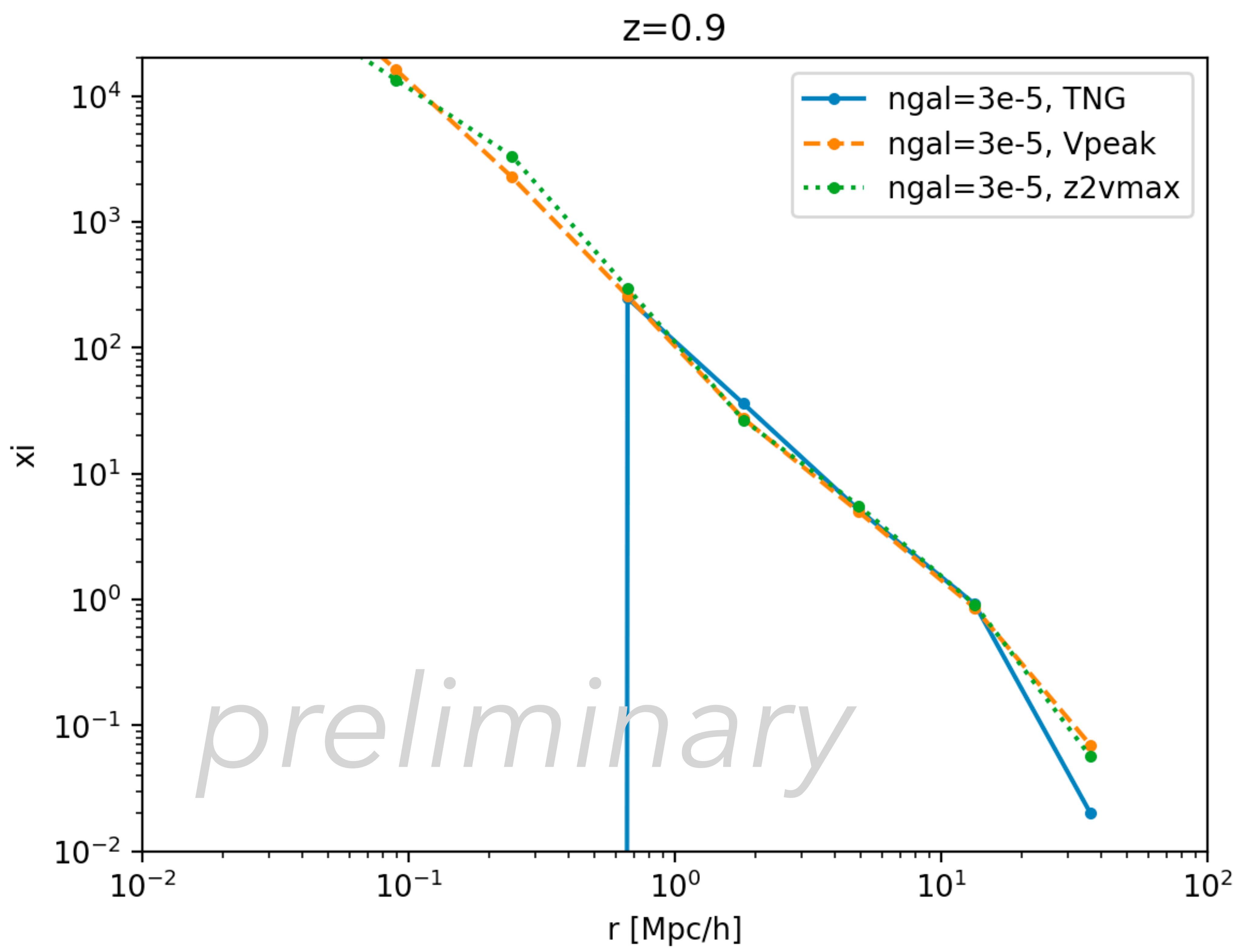
- We search the best field in ~16k mock field constructed in the Uchuu sim.

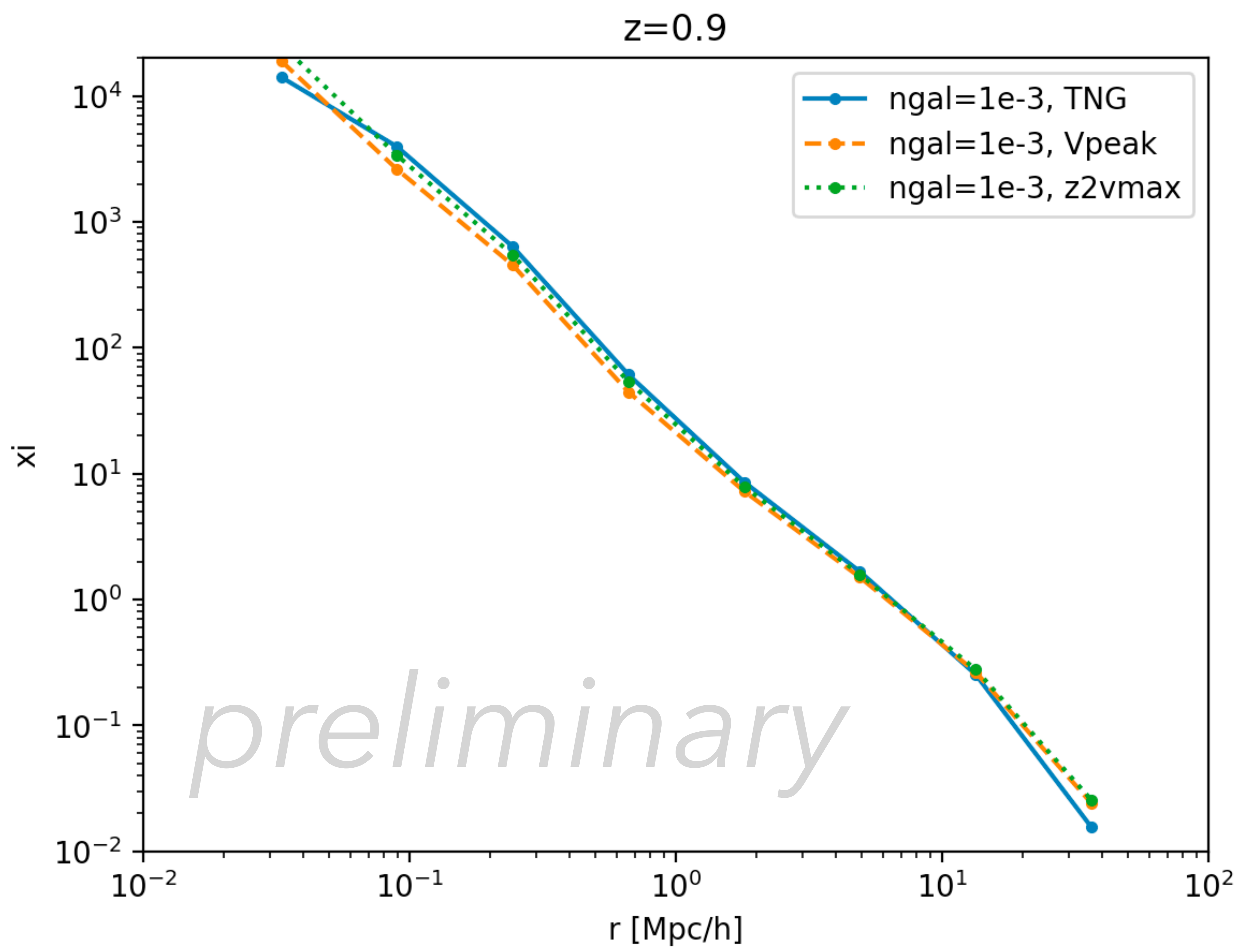




Status report: Revisiting massive galaxy clustering

- FINDING: SHAM with Vmax@z=2 gives the similar clustering to the standard model with Vpeak.
  → SHAM with Vpeak works well because it is a nice tracer of gravitational potential at cosmic noon (the peak of star formation)?





F10

Constraining Mixed Dark-Matter models of WIMPs and Primordial Black Holes from CMB and radio observations

Hiroyuki Tashiro

Nagoya University

公募研究 （21H05459）

高赤方偏移21cm線観測によるダークマターモデルの検証

Redshifted 21 cm line observation

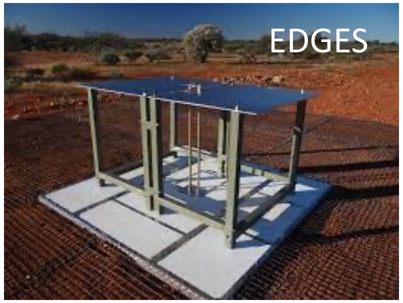
Line signal from hyperfine transition of neutral hydrogen

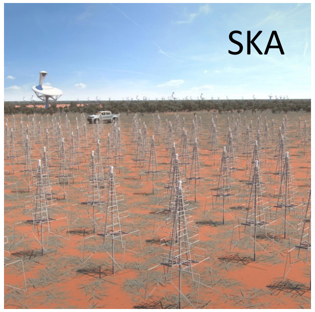
$$\delta T_b(\nu) \sim 27 x_{\rm HI}(1+\delta_i)\left(1-\frac{T_\gamma}{T_s}\right)\left(\frac{H}{dv_r/dr+H}\right)\left(\frac{1+z}{10}\right)^{1/2}\left(\frac{0.15}{\Omega_m h^2}\right)^{1/2}\left(\frac{\Omega_b h^2}{0.023}\right)[\rm mK]$$

Signal depends on the physical property of hydrogen gas
(density, ionization rate, temperature etc.)

access the IGM gas in the cosmic dawn $(10 \lesssim z \lesssim 20)$

- Global signal : EDGES, SARASIII
- Fluctuations : SKA (in the late 2020's)





- Research purpose

Can redshifted 21cm observations tell us the nature of DM?

Investigate the effect of DM on the IGM in the cosmic dawn

Mixed Dark-Matter Scenario of WIMPs and PBHs

In collaboration with K. Kadota (HIAS-UCAS)

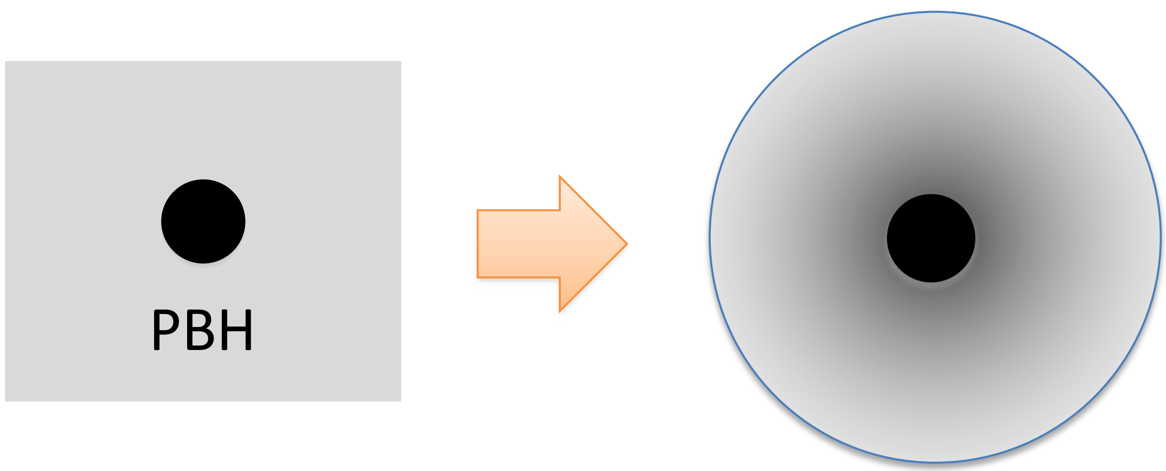
PBH abundance

$$\Omega_{\rm PBH} = f_{\rm PBH}\Omega_{\rm DM}$$

WIMP abundance

$$\Omega_{\rm WIMP} = (1 - f_{\rm PBH})\Omega_{\rm DM}$$

WIMP particles accrete onto PBH and WIMP halo form around PBH



WIMP halo

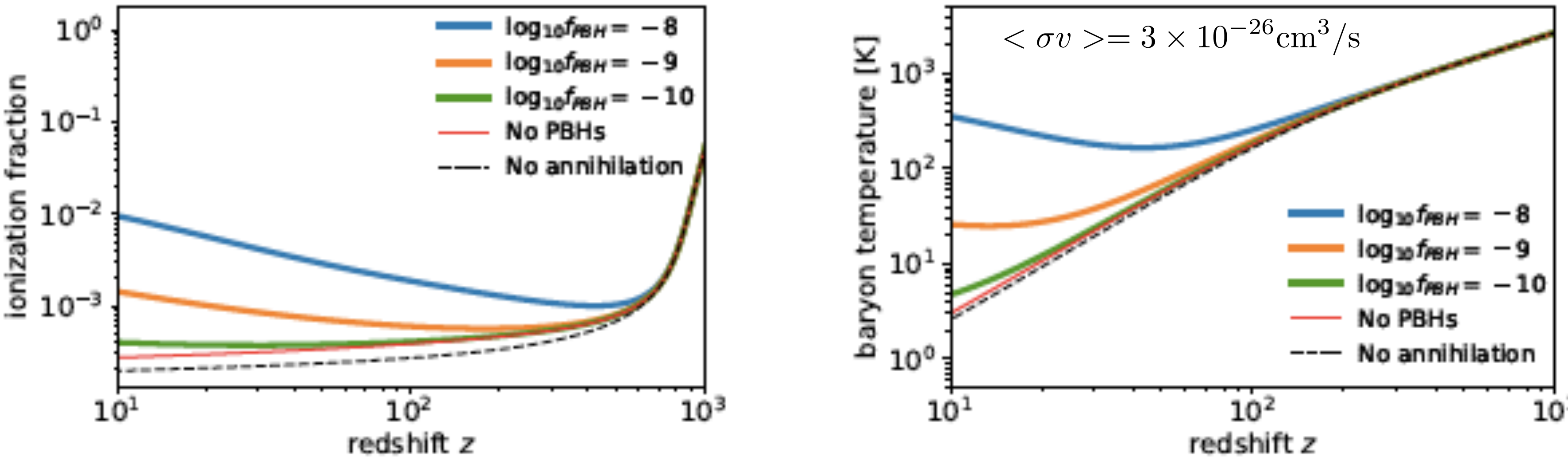
Density profile

$$\rho(r) \propto r^{-4/9}$$

Annihilation rate: $\Gamma \propto n_{\rm WIMP}^2$

PBH enhance the WIMP annihilation

Ionization and thermal history in the PBH-WIMP scenario



Ionization and heating are sensitive to the PBH abundance

We evaluate the global 21cm signals

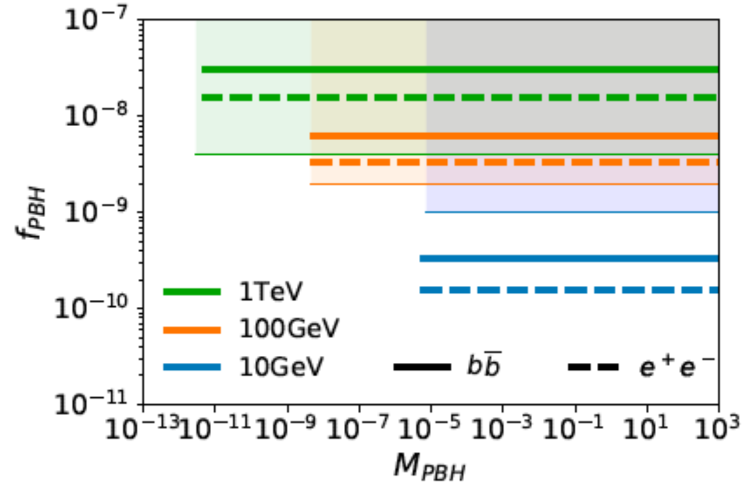
EDGES observation : global 21cm absorption signal around

$$|\delta T_b| \approx 0.5^{+0.5}_{-0.2} \mathrm{K}$$

(Bowman et al. 2018)

EDGES constraint

$$m_\chi = 100 \text{ GeV}$$
$$f_{\rm PBH} < 2\times 10^{-9}$$
$$(M_{\rm PBH} \gtrsim 10^{-8}\ M_\odot)$$
$$m_\chi = 1 \text{ TeV}$$
$$f_{\rm PBH} < 4\times 10^{-10}$$
$$(M_{\rm PBH} \gtrsim 10^{-12}\ M_\odot)$$



γ-ray obs: colored regions (Adamek et al. 2019)

CMB obs: colored lines (HT & Kadota 2021)

stronger constraint than γ-ray or CMB obs.

Next steps

- Recently, global 21cm observation, SARAS 3, reported the non-detection of the EDGES absorption signal
  ⇨ evaluate 21cm fluctuations by the future observation, SKA
- Astrophysics condition (the efficiency of the star and galaxy formation) can easily modify the 21cm signal
  ⇨ Improve the model including first galaxies and stars

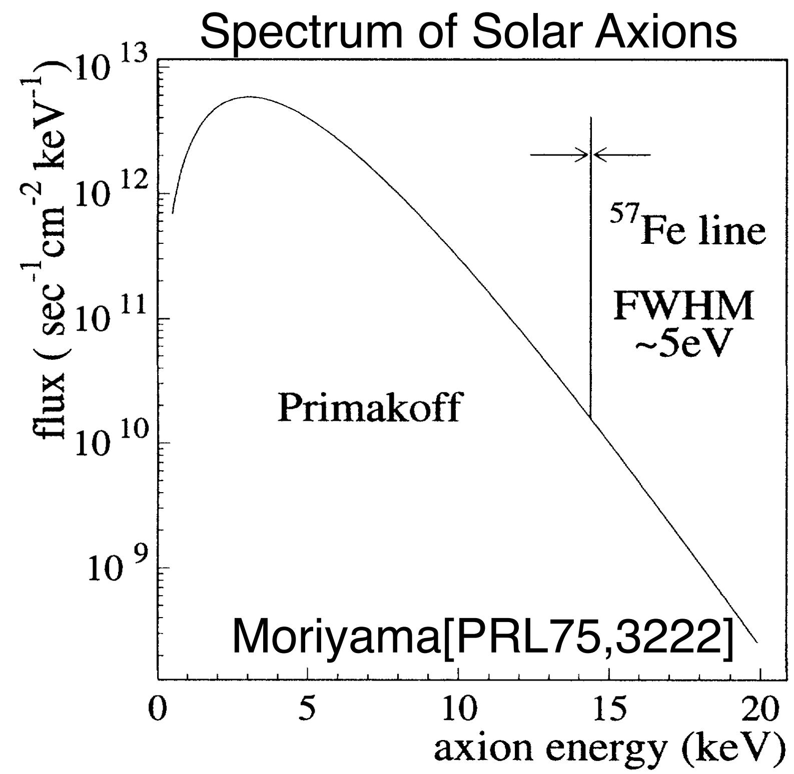
F11

I

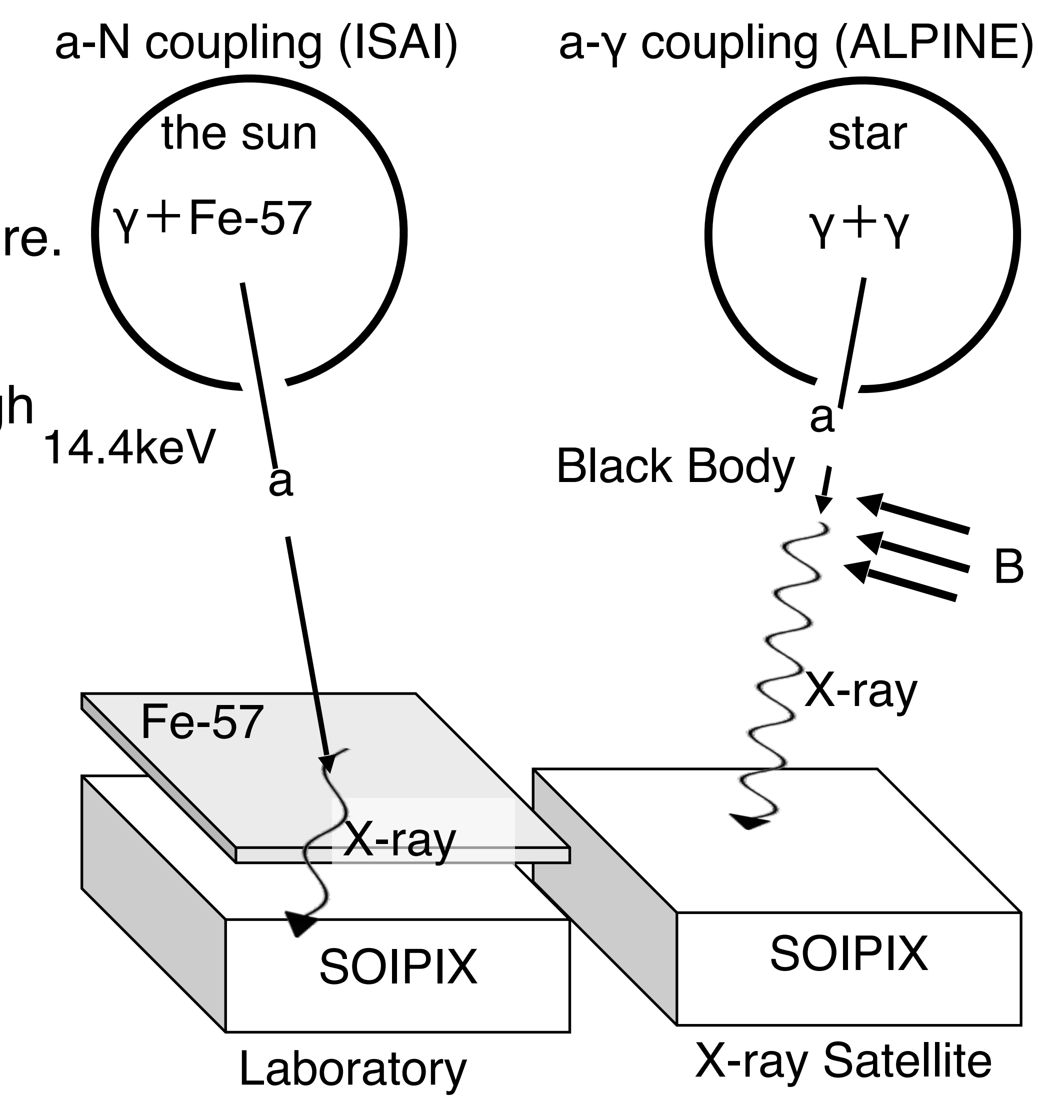
Axion search experiments from ground and space with new X-ray pixel detectors

新型X線ピクセル検出器で地上と宇宙から迫る相互作用の混合がないアクシオン探索実験

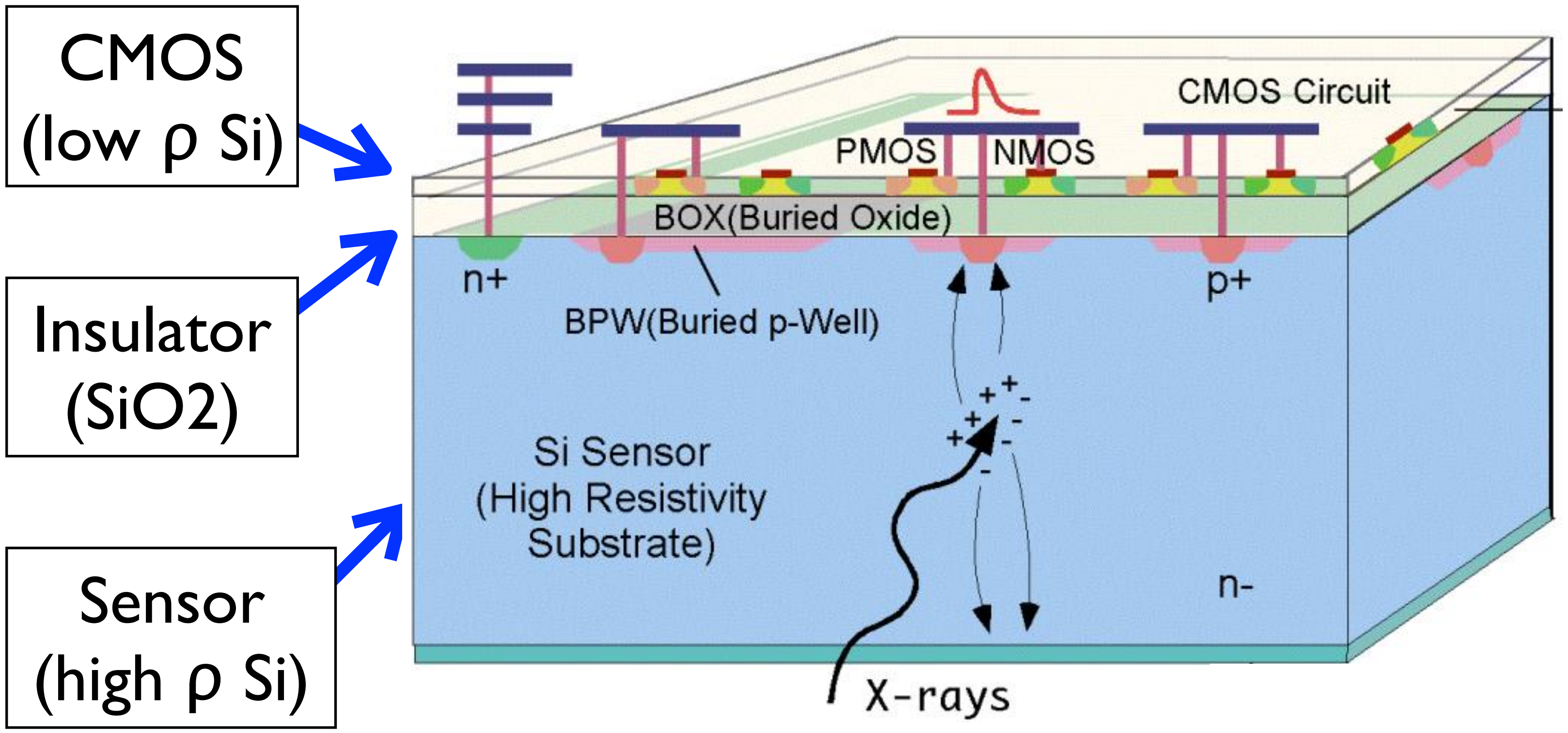
T. Tsuru, T. Ikeda (Kyoto),
T. Fujii (Kyoto U., Osaka MU.), K. Miuchi (Kobe U.), Y. Onuki, Y. Inoue (U. Tokyo)



- XENON1T: a signal that can be interpreted as a solar axion origin. [PRD 102, 072004]
- The signal is a mixture of a-e, a-γ, a-N.
- Launch two experiments to measure each interaction without mixture.
- ISAI : table-top experiment for a-N interaction
  - Monochromatic solar axions produced at the solar center through a-N interaction with Fe-57.
  - Detect the solar axions as 14.4 keV X-rays by converting the axions with a Fe-57 target placed in the laboratory.
- FORCE-ALPINE observation for a-γ interaction
  - Black-body stellar axions produced through the Primakoff conversion at the stellar center
  - Observe the stellar axions as black-body X-rays converted through the inv-Primakoff by interstellar magnetic field.
- Both experiments use our original pixel detecter “Trigger-Output Event-Driven X-ray SOIPIX”.



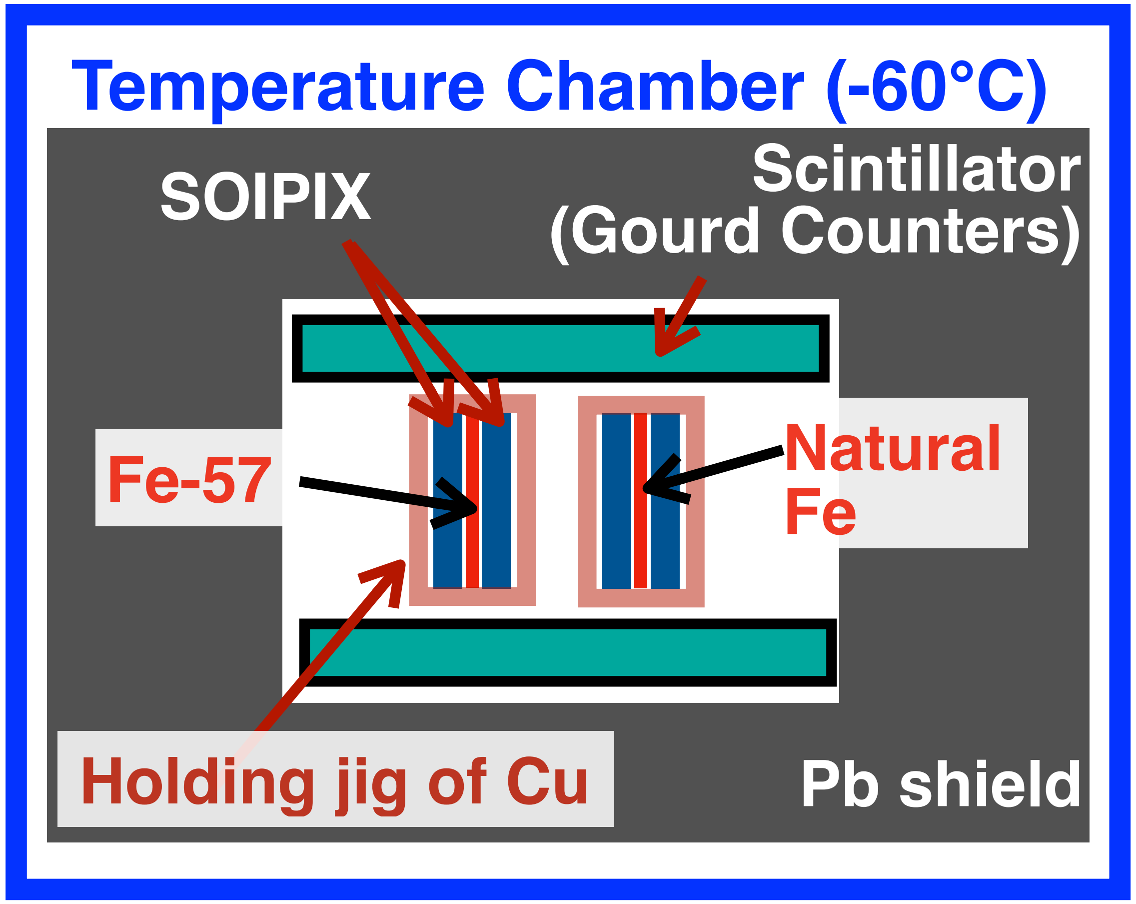
Trigger Output Event-Driven X-ray SOIPIX



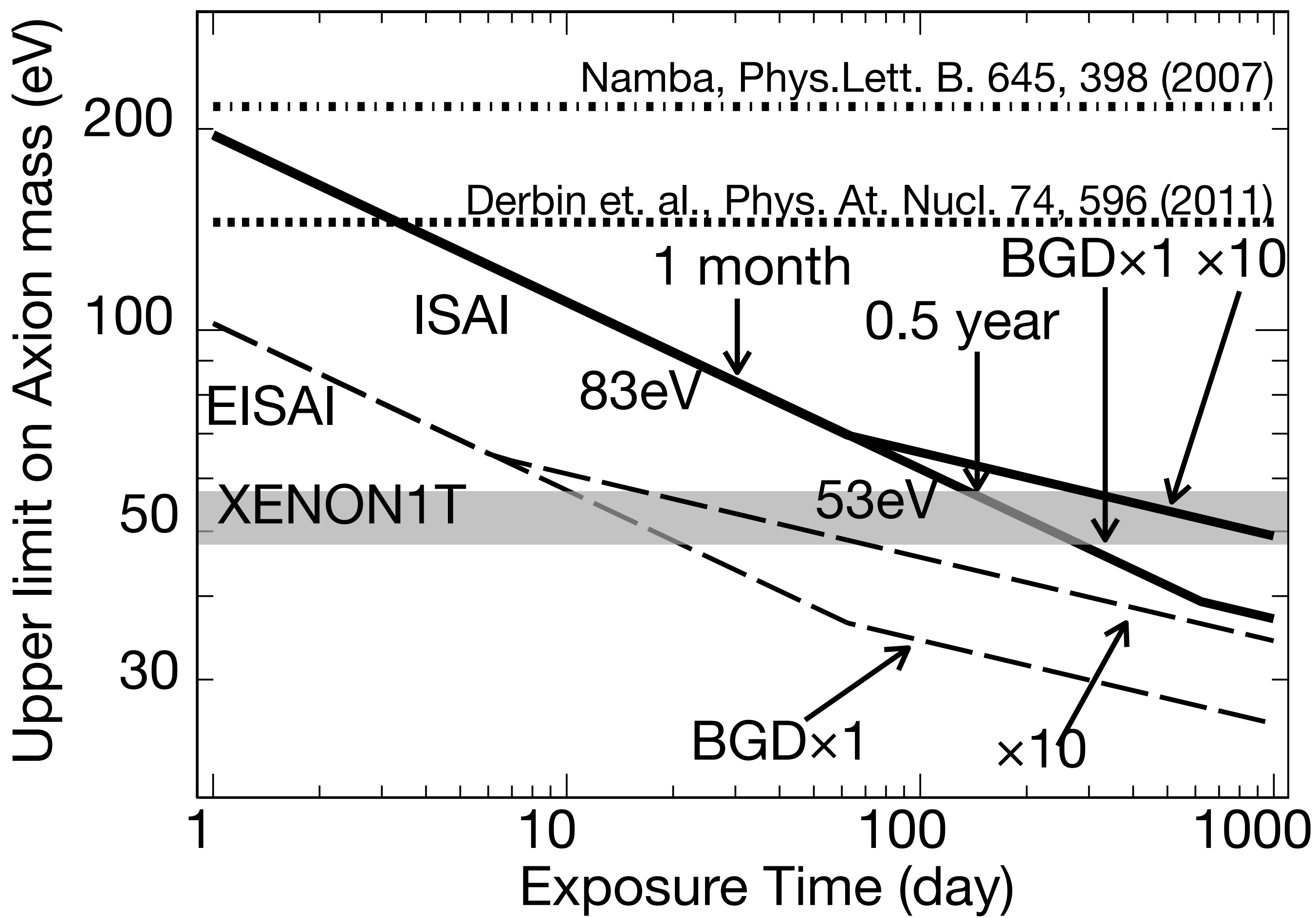
	PIN Photodiode	CCD	SOIPIX (XRPIX7)	DSSD	TES
ΔE (FWHM)	3500 eV	200 eV	250 eV	1000 eV	10 eV
Anti-coincidence	applicable	not applicable	applicable	applicable	applicable
Particle Track (imaging)	not applicable	good	good	not impossible	not impossible
Large Area	good	good	good	good	not impossible

- Monolithic active pixel sensors based on a Silicon-On-Insulator (SOI) CMOS technology
- We have been developing X-ray SOIPIXs for the Japanese FORCE satellite [SPIE 10709, pp.107090H; SPIE 10699, pp.106992D-1].
- Immediate readout of only the hit pixels with its high time resolution of ~10 μsec
  - An event trigger output function implemented in each pixel
  - Background reduction by adopting an anti-coincidence technique
- Nearly Fano-limited energy resolution
  - Suitable to identify 14.4 keV X-rays converted from the solar axions
- Large Size with 24.6mm × 15.3mm
- Thick Si depletion layer ~300μm
  - High QE for X-rays > 10 keV
- Small pixel with 36μm × 36μm
  - Background reduction with particle tracking

ISAI (Investigating Solar Axion by Iron-57)



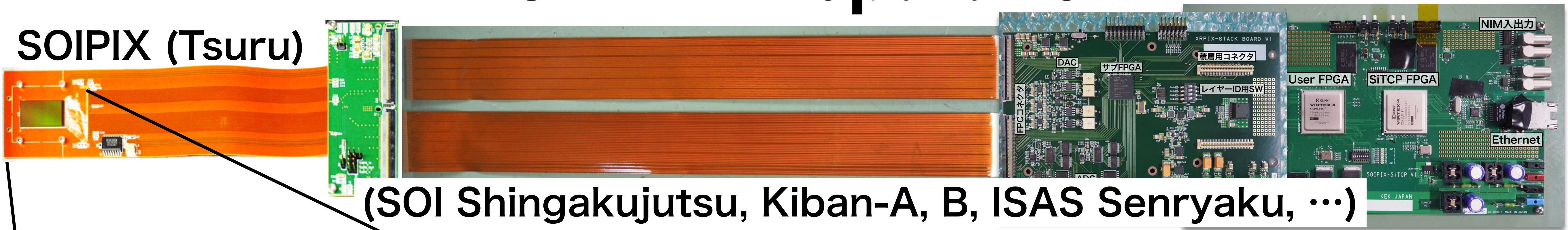
- Fe-57 film with the mass of 127mg and the thickness of 40μm
- Four SOIPIX sensors mounted on rigid-flex PCBs are used
  - two SOIPIXs sandwich Fe-57
  - two sandwich natural Fe (no Fe-57)
- shielded by Pb shield installed in a temperature chamber
- guard counters with grids of triangular scintillators



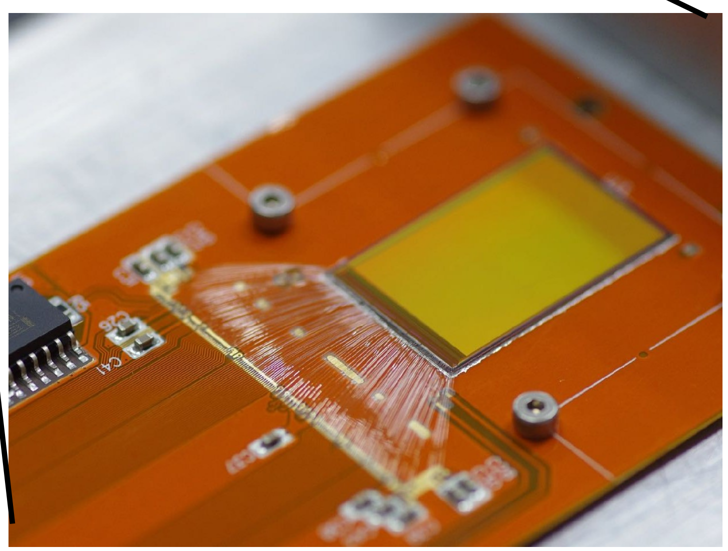
- Predicted upper limits of axion mass for the ISAI and EISAI experiments
- BGDx1: case of background predicted by Onuki et al. (2019) [NIM A, 924, 448]
- BGDx10: case of 10 times higher background than the prediction.
- A 0.5-year (BGDx1) or 1-year (BGDx10) exposure is predicted to reach the XENON1T result.

ISAI in Preparation

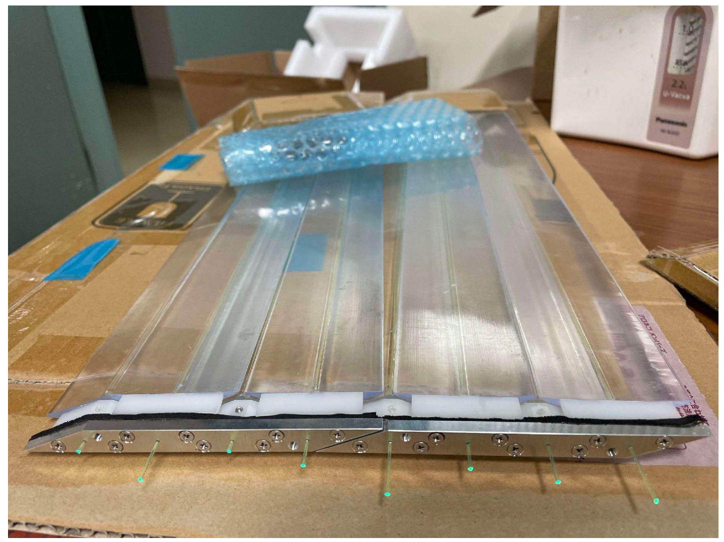
SOIPIX (Tsuru)

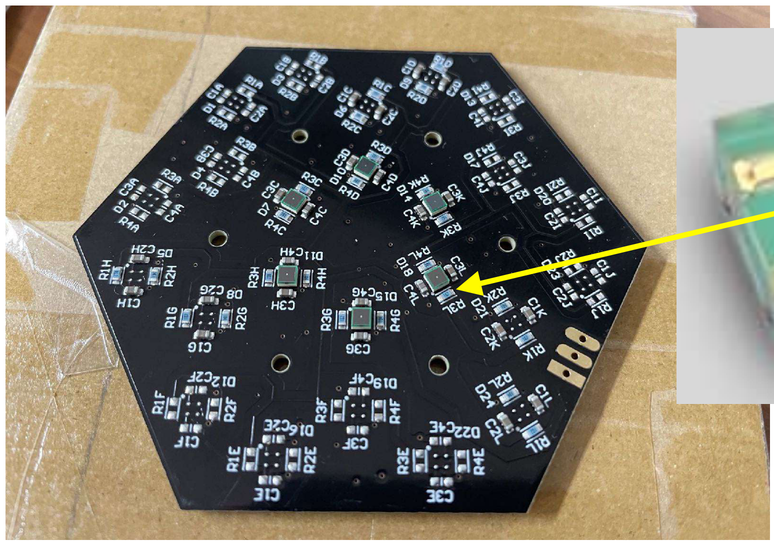


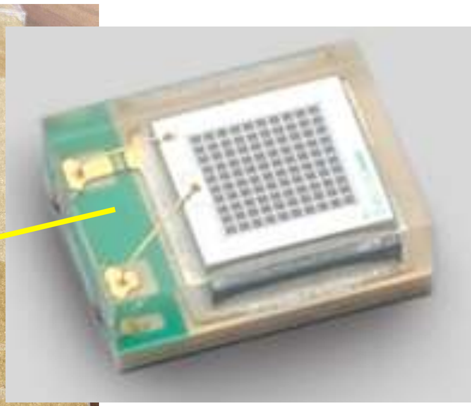
(SOI Shingakujutsu, Kiban-A, B, ISAS Senryaku, …)



Low BGD Flex PCB (Onuki)

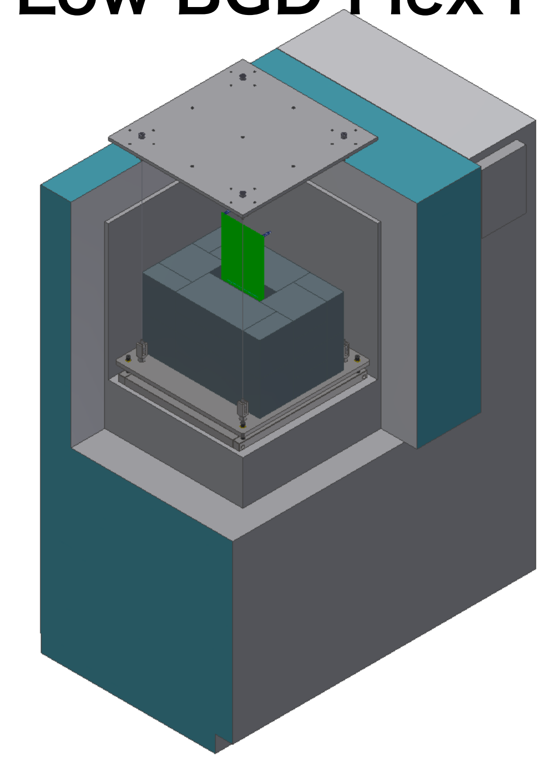




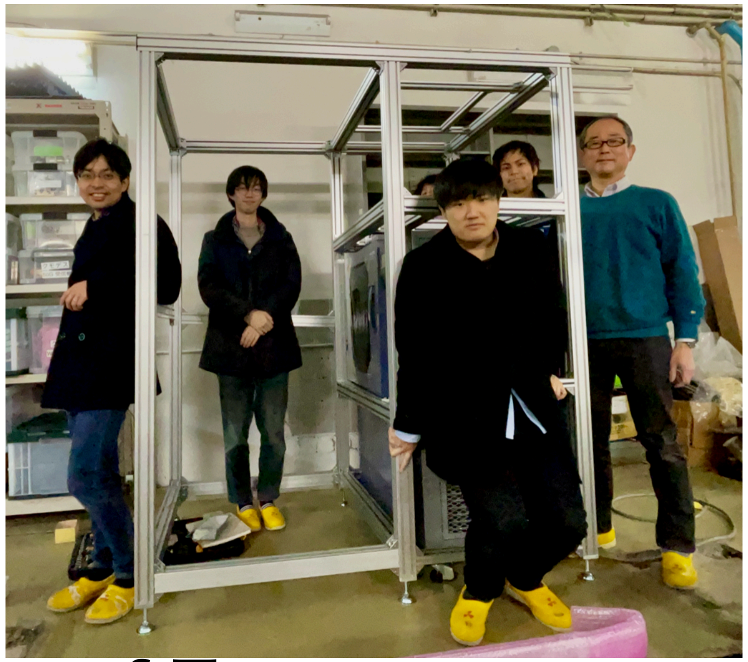


MPPC

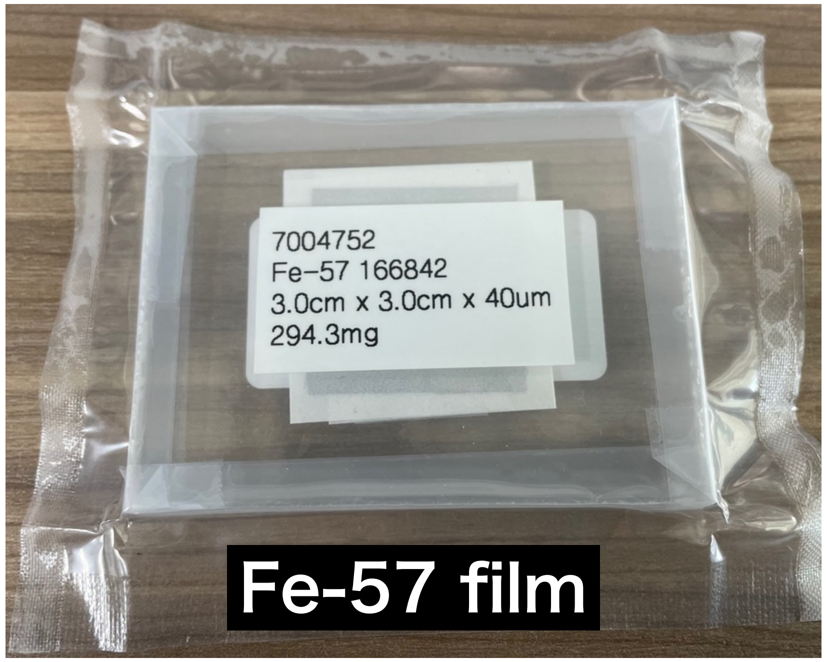
Triangle Scintillator (Fujii)



Shield Design (Onuki)



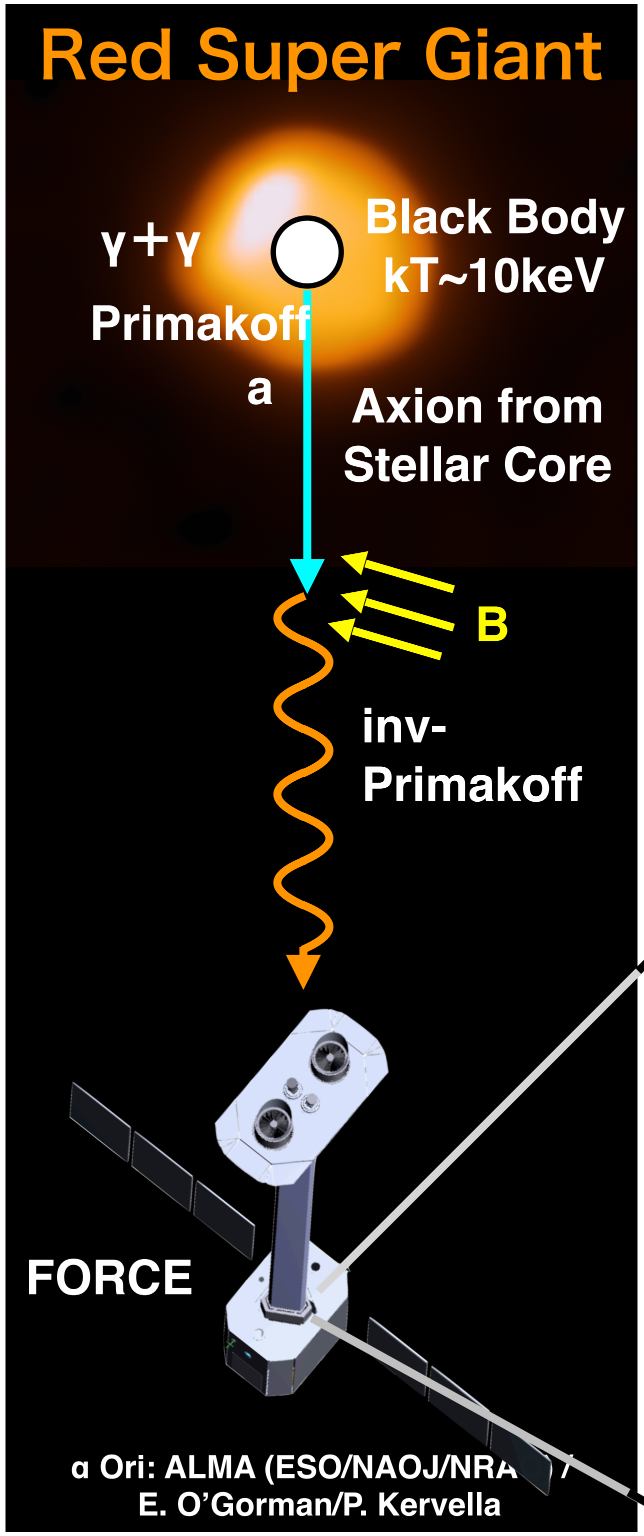
Delivery of Temperature Chamber to Kyoto



2.5 million yen (Chousen Kaitaku)

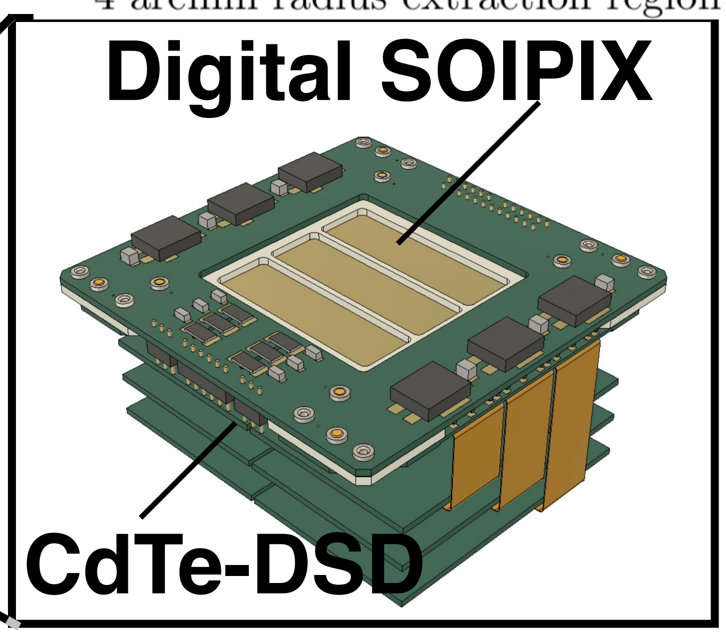
FORCE-ALPINE (Axion Like Particle Investigation at Novel Extraterrestrial objects)

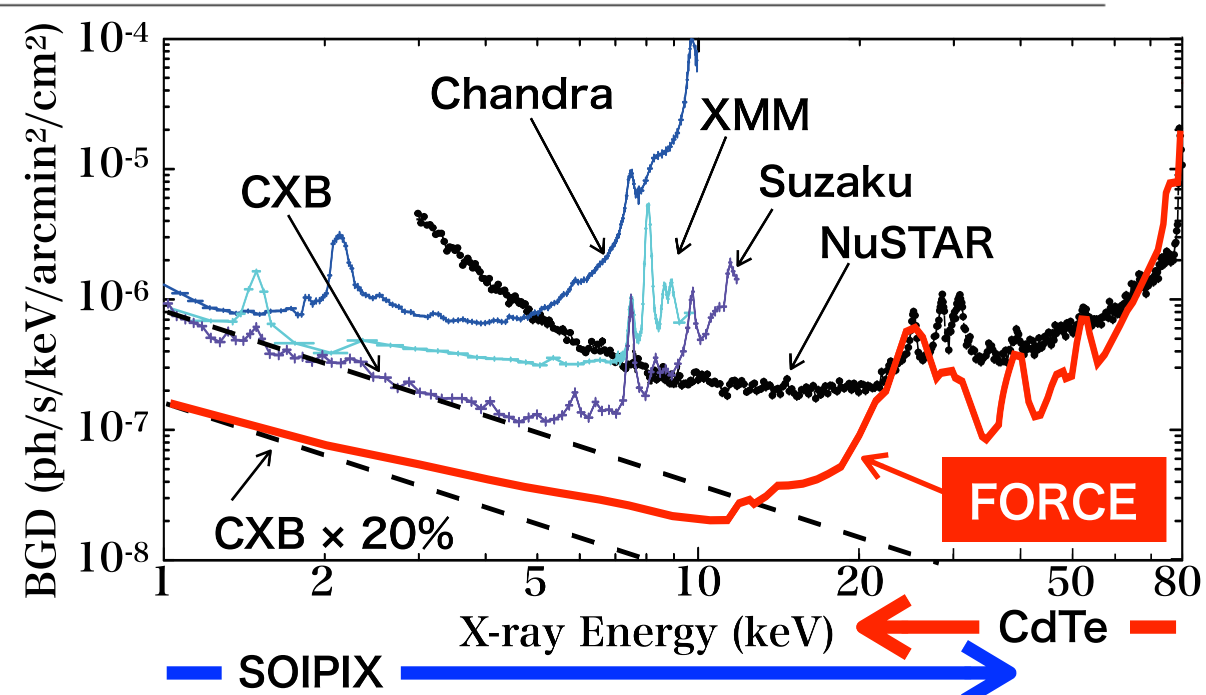
- Axions from core of a red-giant star are converted into X-rays by the interstellar magnetic field through the inv-Primakoff conversion [arXiv:1711.00345, PRL 126,031101].
- We observe the X-rays with the FORCE satellite equipped with SOIPIXs, whose sensitivity is one order of magnitude higher than that of the NuSTAR satellite.
- We will apply the background rejection function developed for the ISAI experiment to those for the FORCE satellite.



Parameter	FORCE (requirement)	NuSTAR	ASTRO-H (HXT & HXI)
angular resolution (HPD)	$<15''$	$58''$	$1.7'$
bandpass (keV)	1–79	3–79	5–80
effective area (cm^2@30 keV)	>200	184*	198*
fov (50% resp. @30 keV)	>49 $arcmin^2$	∼85 $arcmin^2$	∼36 $arcmin^2$
timing resolution	several × 10 μs	2 μs	several × 10 μs
energy resolution (FWHM)	<300 eV at 6 keV comparable with HXI	400 eV at 10 keV 900 eV at 68 keV	900 eV at 14 keV 1500 eV at 60 keV

* 4 arcmin radius extraction region





F12

D03 Quantum Gravity Constraints on Dark Matters

Toshifumi Noumi (Kobe U)

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

using consistency conditions of quantum gravity!

cf. C01 group of Yamazaki-san

March 29 2022 @ 学術変革シンポジウム

Motivation

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

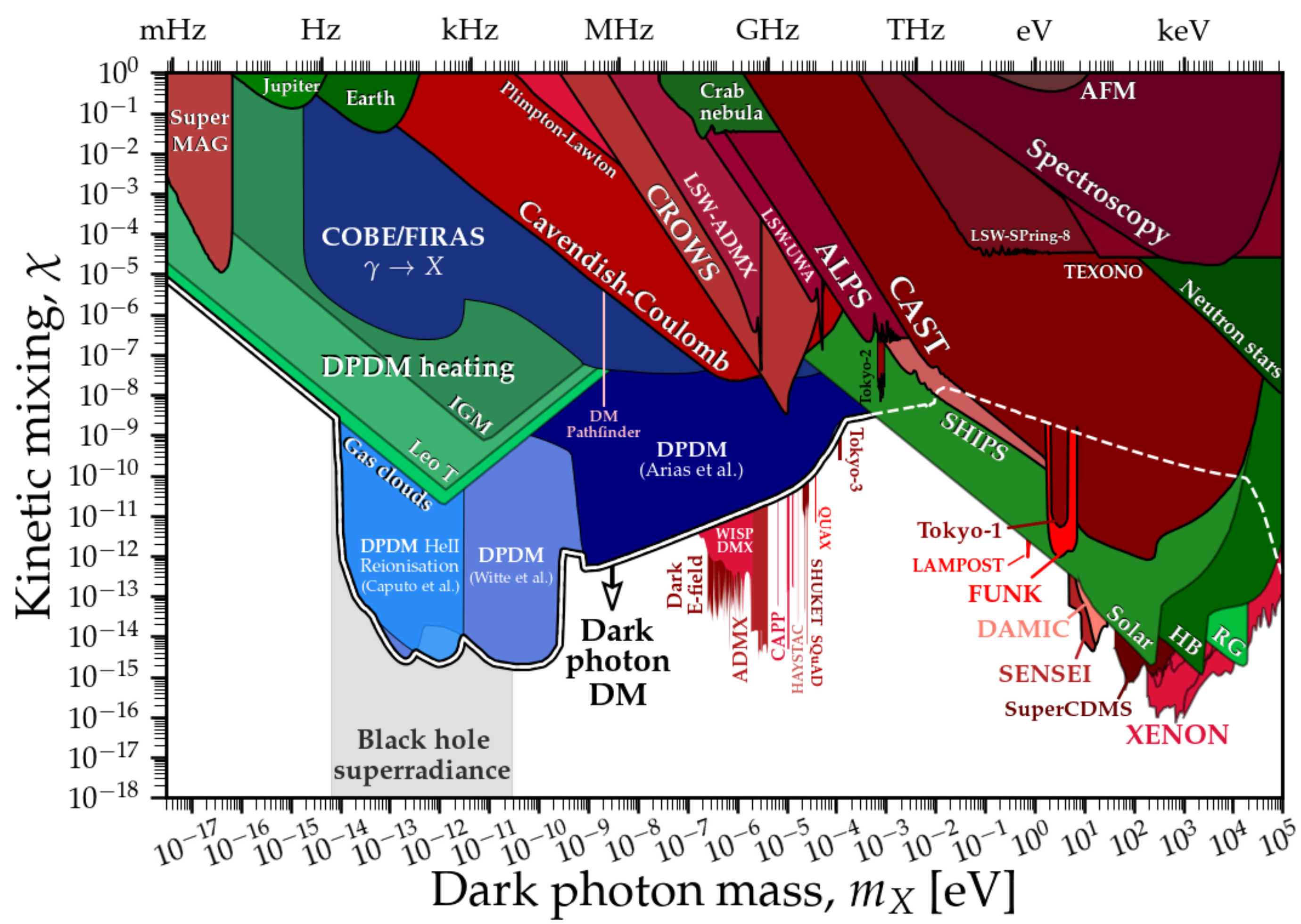
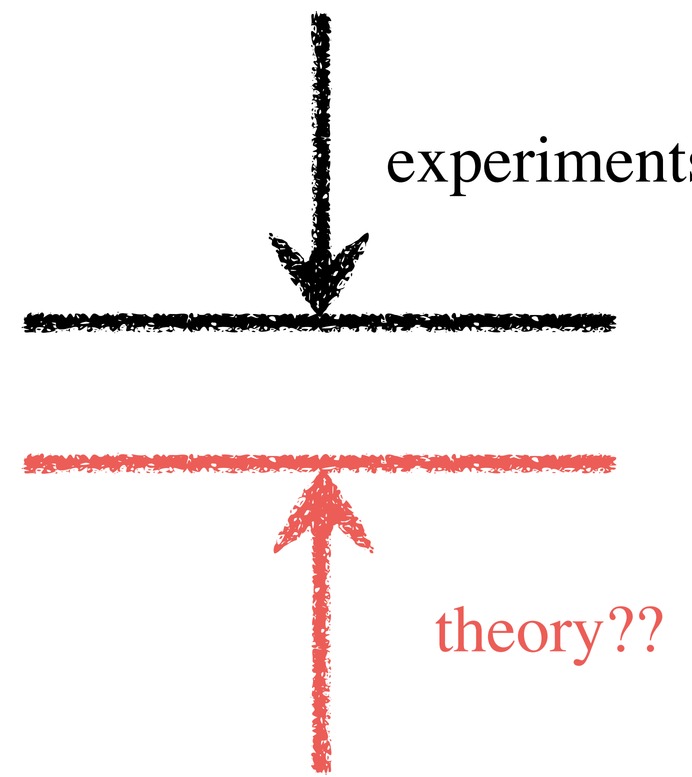


Fig: dark photon search as an example



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

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

Its magnetic version states that $gM_{\rm Pl} \gtrsim \Lambda$ (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 2021

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 $\Lambda < \sqrt{\frac{1440}{11}} y_e \sin\theta_W M_{\rm Pl}$.

- 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.

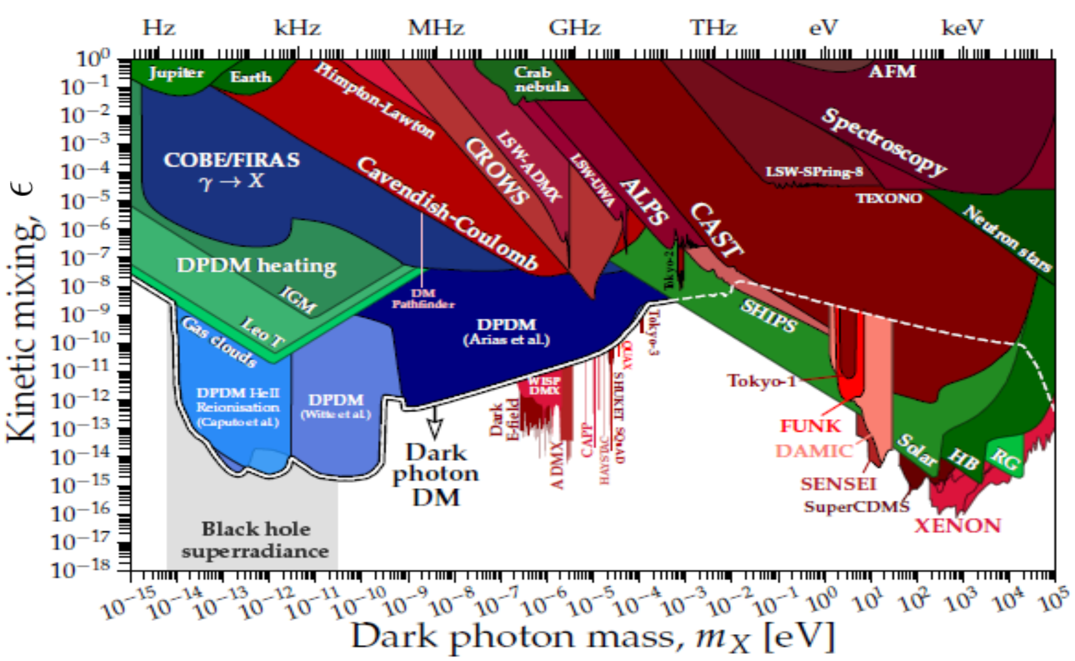
Prospects for 2022

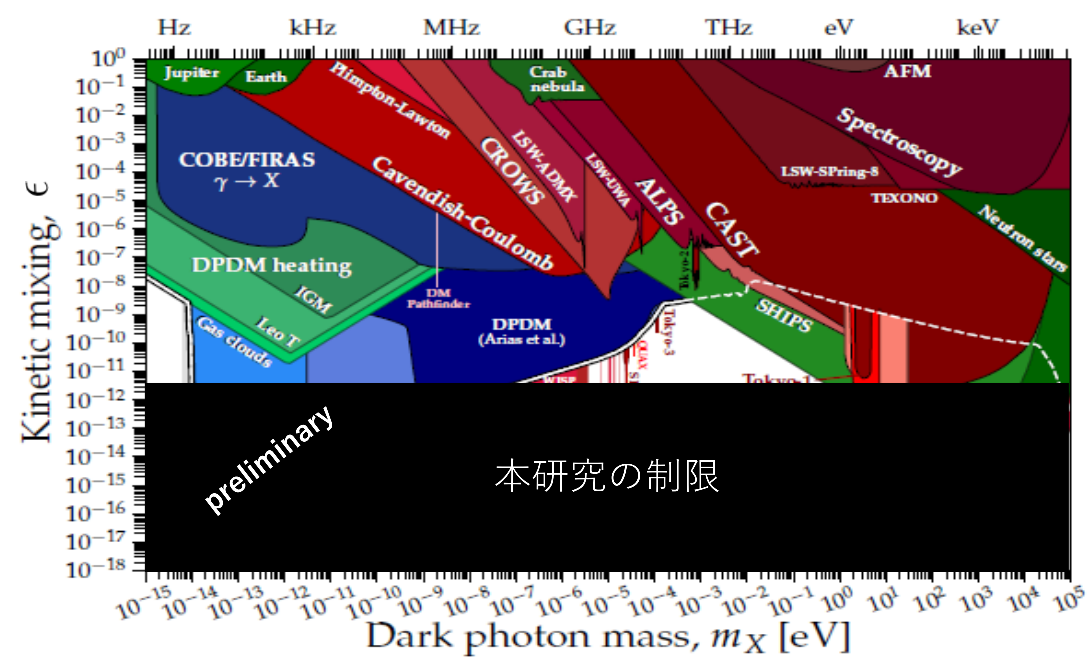
Our ongoing works include the following two directions:

1) Generalization of the SM analysis to DM models (and other phenomena).

2) Revisit technical assumptions from Regge analysis, BH thermodynamics etc.

A preliminary result on dark photon [TN-Sato-Tokuda in progress]:





Further implications for DM models are discussed with people in the C01 group

F13

2021 and 2022

Search for Dark Matter of Axion and Dark Photon at the LHC-ATLAS Experiment

Junichi TANAKA

ICEPP, UTokyo

2022 March 29

PhD students: Gen Tateno and Tingyu Zhang

UTokyo

ICEPP
The University of Tokyo

Introduction

- LHC-ATLAS has been searching for DM candidates, in particular, our analysis team (ICEPP, UTokyo and ATLAS-Japan physics group) has focused on SUSY search: strong, stop and now EW SUSY. So far there is no indication of SUSY. (Needless to say, LSP of SUSY is a DM candidate.)

- In this project, we try different approaches, that is, [1] Axion-like DM and [2] Dark-sector search in the LHC-ATLAS experiment. Two PhD students have worked on these subjects (for their PhD thesis) now:
  [1] O(TeV) Axion-like particle by Gen Tateno (D3*, UTokyo) * … from this April.
  [2] O(MeV-GeV) Dark Photon by Tingyu Zhang (D2**, UTokyo) ** … from the last Oct (entered UT in the fall)

- In this Henkaku-A, a similar mass region and physics (dark photon) will be investigated by Belle II, so that our project can be complementary.

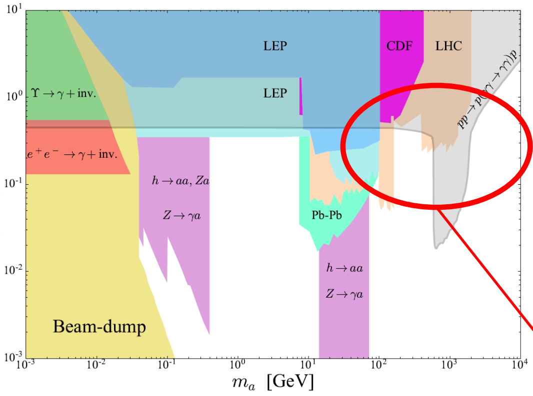
ICEPP
The University of Tokyo

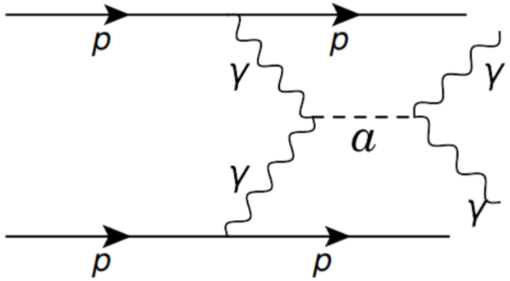
Gen Tateno (PhD student)

Axion-Like Particle (ALP) Search

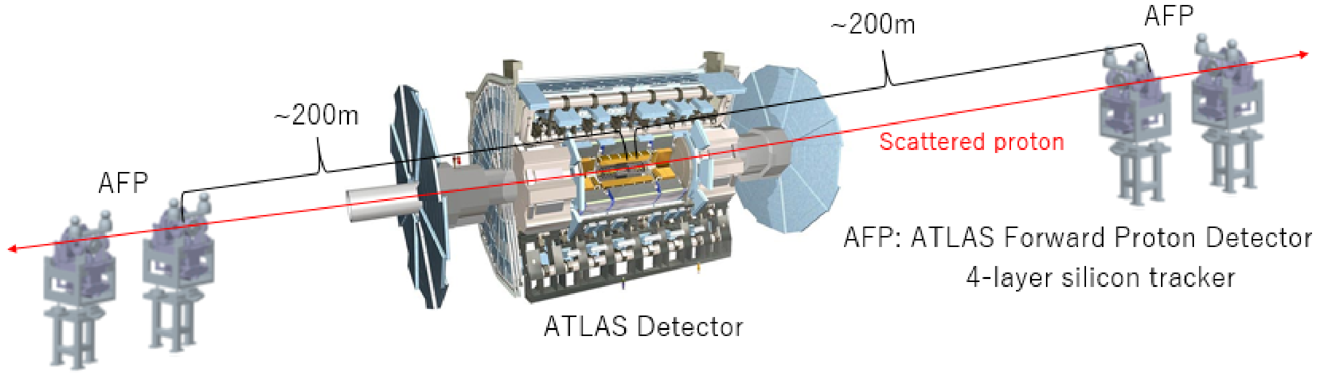
$$\mathcal{L} = \frac{1}{2}\partial^\mu a \partial_\mu a - \frac{1}{2}m_a^2 a^2 - \frac{1}{f} a F^{\mu\nu}\tilde{F}_{\mu\nu}$$

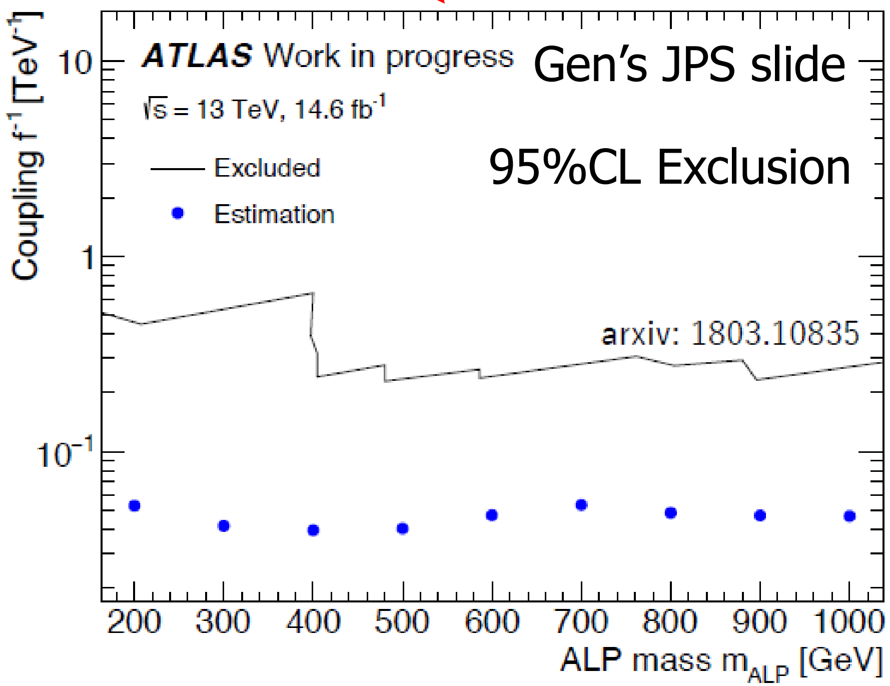
arXiv:1803.10835





Use LHC as a photon-photon collider





AFP (ATLAS Forward Proton) detector
→ "Approximately elastic" scattered protons are detected.

Due to the limitation of AFP availability, we can use only a part of Run 2 data (14.6 fb^{-1}).

We have developed how to estimate BG using real data.
→ Gen reported in the last JPS (15aA561-11).

Difficulty and fun: almost all things have to be done by Gen since this type of studies is not major at ATLAS.

Plan: a conference note is expected around this autumn.

ICEPP
The University of Tokyo

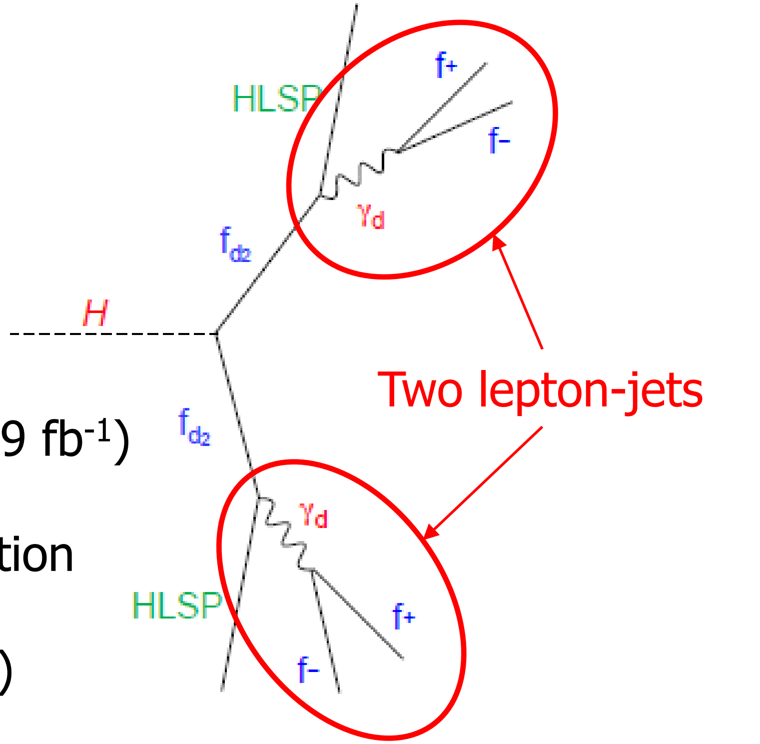
Tingyu Zhang (PhD student)

Dark Photon Search

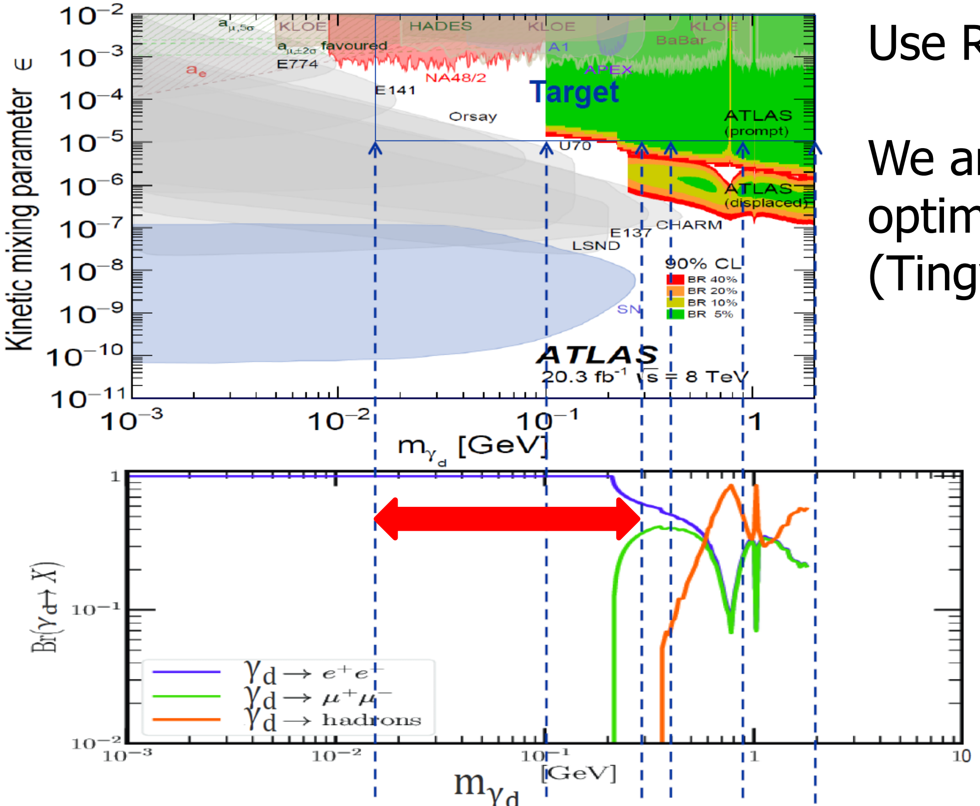
FRVZ (Falkowski–Ruderman–Volansky–Zupan) model

We use 125GeV Higgs as a portal to access the dark photon sector.

The target mass of dark photon is O(100 MeV-GeV).
→ the dark photons can be boosted.
Two fermions from a dark photon are collimated.
We reconstruct this "two collimated fermions" as a lepton-jet.
In our team, we focus on $\gamma_d \rightarrow e^+e^-$. ($\gamma_d \rightarrow \mu^+\mu^-$ by Italian team)
→ our target mass is mainly 0.02 - 0.3 GeV. (almost prompt decay)



Additional $U_d(1)$
→ mix with $U_Y(1)$
by kinetic mixing ε



Use Run 2 full data (139 fb^{-1})

We are doing the selection optimization etc.
(Tingyu stays at CERN.)

Difficulty and fun:
a lepton-jet has different properties from a standard isolated lepton.
So, we need to develop its particle ID etc. using ex ML/DL.

Plan: the target conference is the next Moriond.

ICEPP
The University of Tokyo