Non-WIMPs

DarkOn

2017年1月２８日

岸本康宏

Non-WIMPs DM

- なにを想起しますか？

WIMP？

- WIMP miracle！
  - Cosmology
    - Cold dark matter
  - Particle physics
    - Eg: SUSY
      - 強い相互作用の統一
      - Fine tuning
- これらを同時に満たすものなら，10GeV~1TeV位で，ちょうど実験的にも見つけられる

WIMPs？

- WIMPs の定義 by IPMU 松本さん
  - 「Cold DM が熱的生成で出来るもの」
    - 他の要素は忘れる
  - **1 MeV ~100 TeV**
    - 上限は σV のユニタリティから
    - 下限は，CMBのΔN_{eff} から

non-WIPMS？

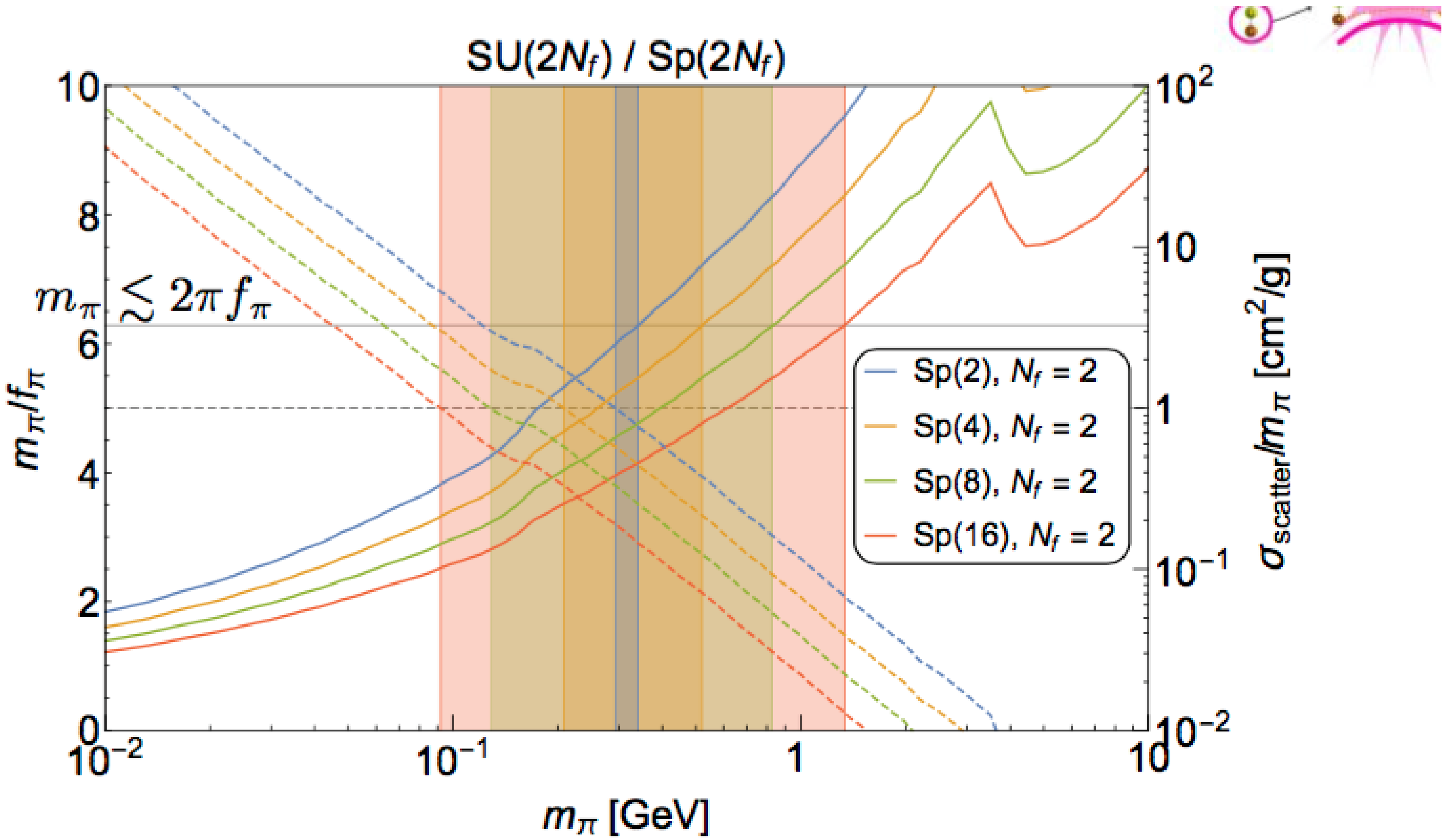
- **<u>Axion, ALPs, HP, …</u>**
- 松本さんの定義に従えば
  「Thermal production scenario でないもの」全部
- この研究会的には
  「WIMPの直接/間接探索の網にかかっていないもの」全部
  - Gravitino
  - keV neutrino
  - Axion, ALPs
  - HP
  - SIMPs (← Thermal だが３体なので）

- どんなのがあるか？
- どうやって探すのか？

WIMPsなのに「non-WIMPs」の例

- SIMPs
  - 強い相互作用の様に,「3体の相互作用ならどうだ？」という考え方

  - U(1)のMediatorが飛ぶらしく, LHCでの探索の話があるようだ



Solid curves: solution to Boltzmann eq. $\frac{m_\pi}{f_\pi} \propto m_\pi^{3/10}$

Dashed curves: along that solution $\frac{\sigma_{\rm scatter}}{m_\pi} \propto m_\pi^{-9/5}$

http://radphys4.c.u-tokyo.ac.jp/leap2016/talks/20160307/Murayama@LEAP2016.pdf

- Gravitino
  - SUSY信じるなら，なぜこれを無視してよいのか？
    - 幸い（ある種のモデルは）結構死んでる（M.Ibe et al., 2016, https://arxiv.org/pdf/1609.06834v1.pdf）

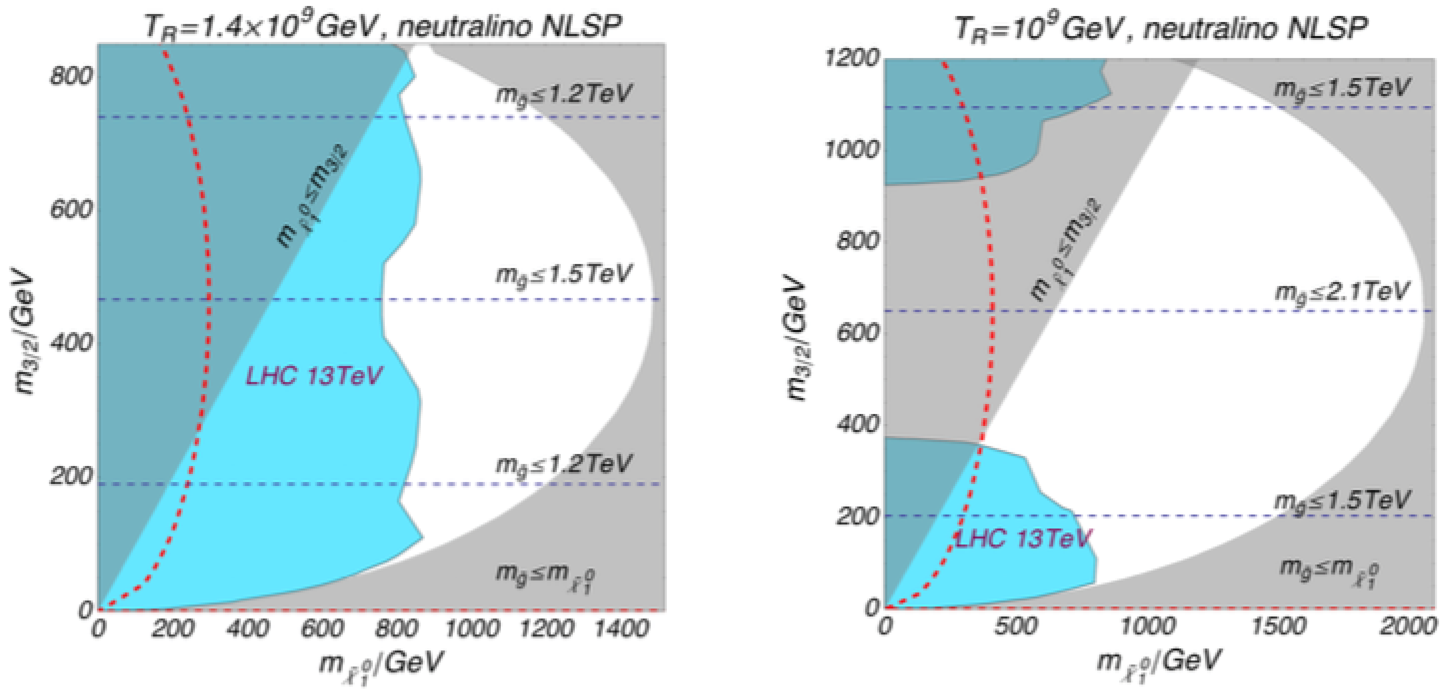


FIG. 3. *Combined constraints for the neutralino NLSP. The reheating temperature is assumed to be $T_R = 1.4 \times 10^9$ GeV (left) and $T_R = 10^9$ GeV (right). The gray shaded regions are excluded where the gravitino is no more the LSP. The blue shaded regions are excluded by the missing momentum searches [62, 65]. The GUT relation of the gaugino mass can be satisfied in the left side of the red dashed line. The horizontal dashed lines show the upper limit on the gluino mass for a given gravitino mass shown in Fig. 1.*

近頃よく聞く ALPs, HP

- ALPとAxion
  - Axion: $g_{a\gamma\gamma} \times m_a = \mathrm{const.}$（QCDのしばり）
  - ALP: そんなのやめちまえ！
- ALP は string theory のLow energy effective field theoryから導出されるという話
- Hidden photon
  - 同様にString
  - 但し，Stringのコンパクト化の時に必ずU(1)ボゾンがでるので，もう少し一般的

- ALP
  - 2γとカップル
    - Axionをやれば，自動的に
  - Coupling to e is expected to be suppressed.

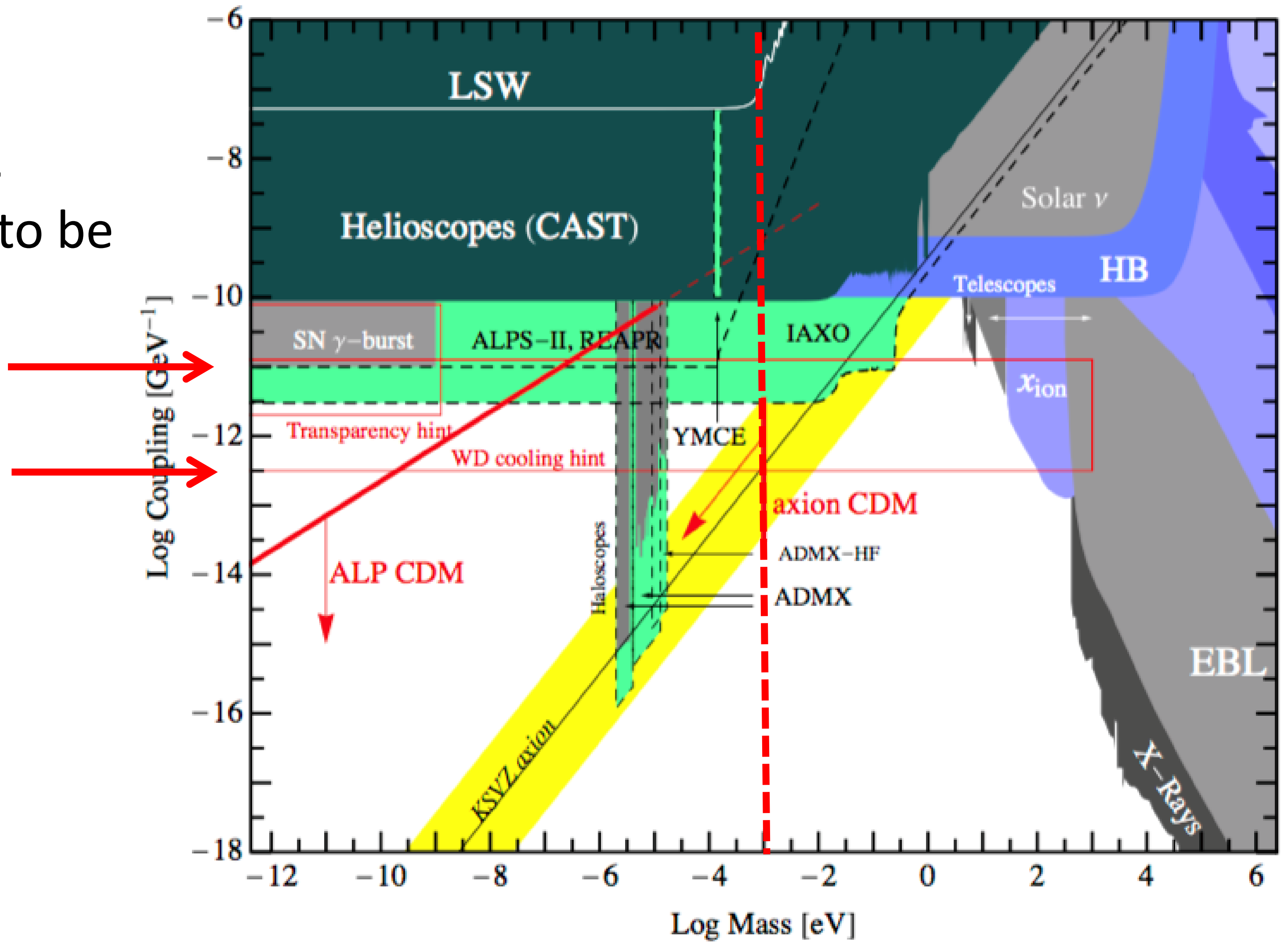
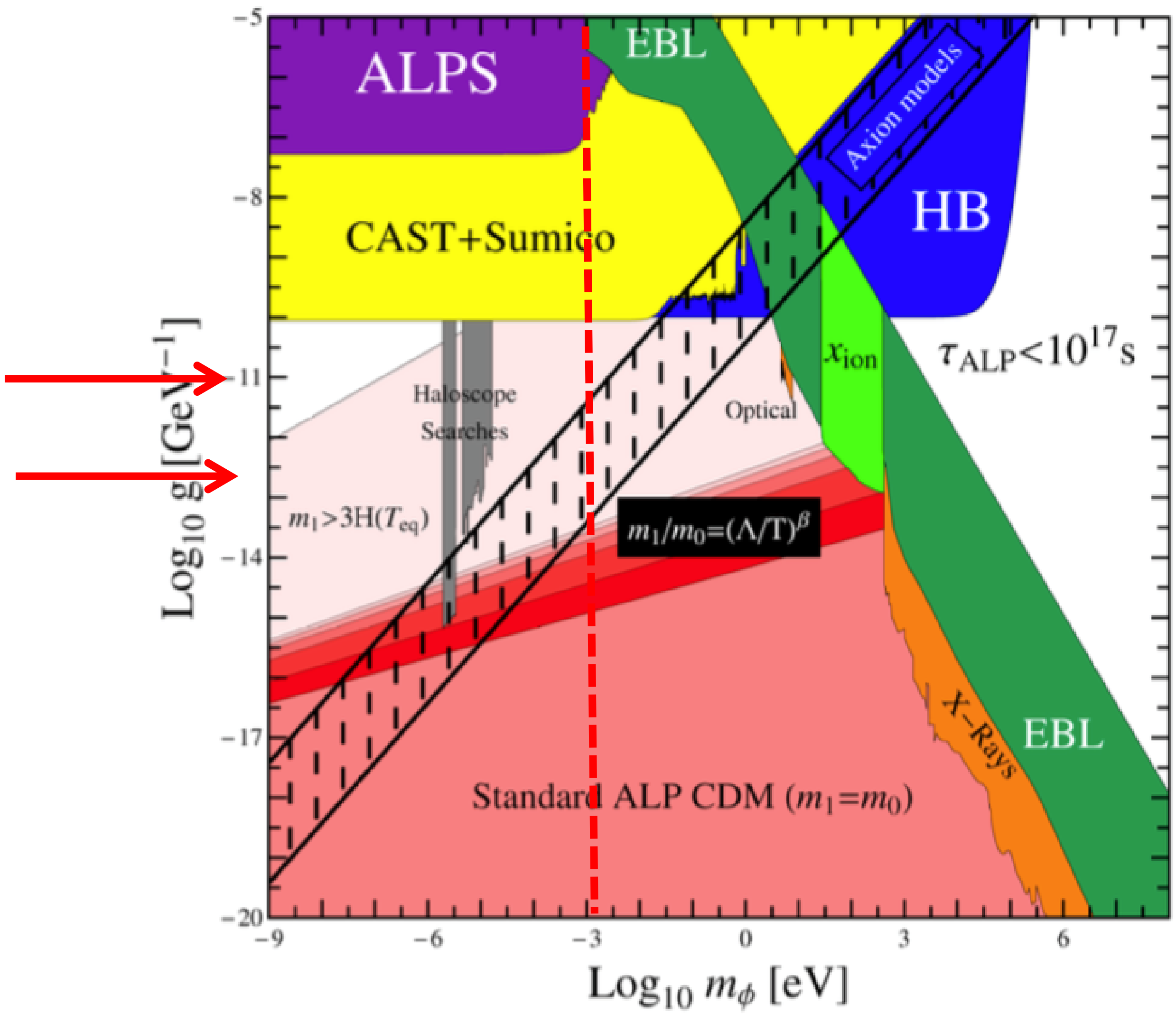


Fig. 2. Axion and ALP coupling to photons vs. its mass (adapted from Refs. [2,3,26,27]). Coloured regions are: generic prediction for the QCD axion, exploiting Eqs. (7) and (9), which relate its mass with its coupling to photons (yellow), experimentally excluded regions (dark green), constraints from astronomical observations (grey) or from astrophysical or cosmological arguments (blue), and sensitivity of planned experiments (light green). Shown in red are boundaries where axions and ALPs can account for all the cold dark matter produced either thermally or non-thermally by the vacuum-realignment mechanism. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Dark Universe 1 (2012) 116–135



JACAP06(2012)013

Figure 1. Parameter space for axions (shaded band labelled "Axion models") and axion-like particles. The regions where they could form DM are displayed in different shades of red (for details see text). The lines representing DM regions are uncertain through a model-dependent multiplicative factor, $\mathcal{N}$, which we have set equal to 1 here. The DM regions move towards larger couplings g, proportional to this factor. The exclusion regions labelled "ALPS", "CAST+Sumico" and "HB" arise from experiments and astrophysical observations that do not require ALP dark matter (for a review, see [38]). The remaining constraints are based on ALPs being DM and are described in the text.

- HP
  - PhotonとMix
  - Milichargeも
  - Axion探索との比較では,
    - 磁場が要らない

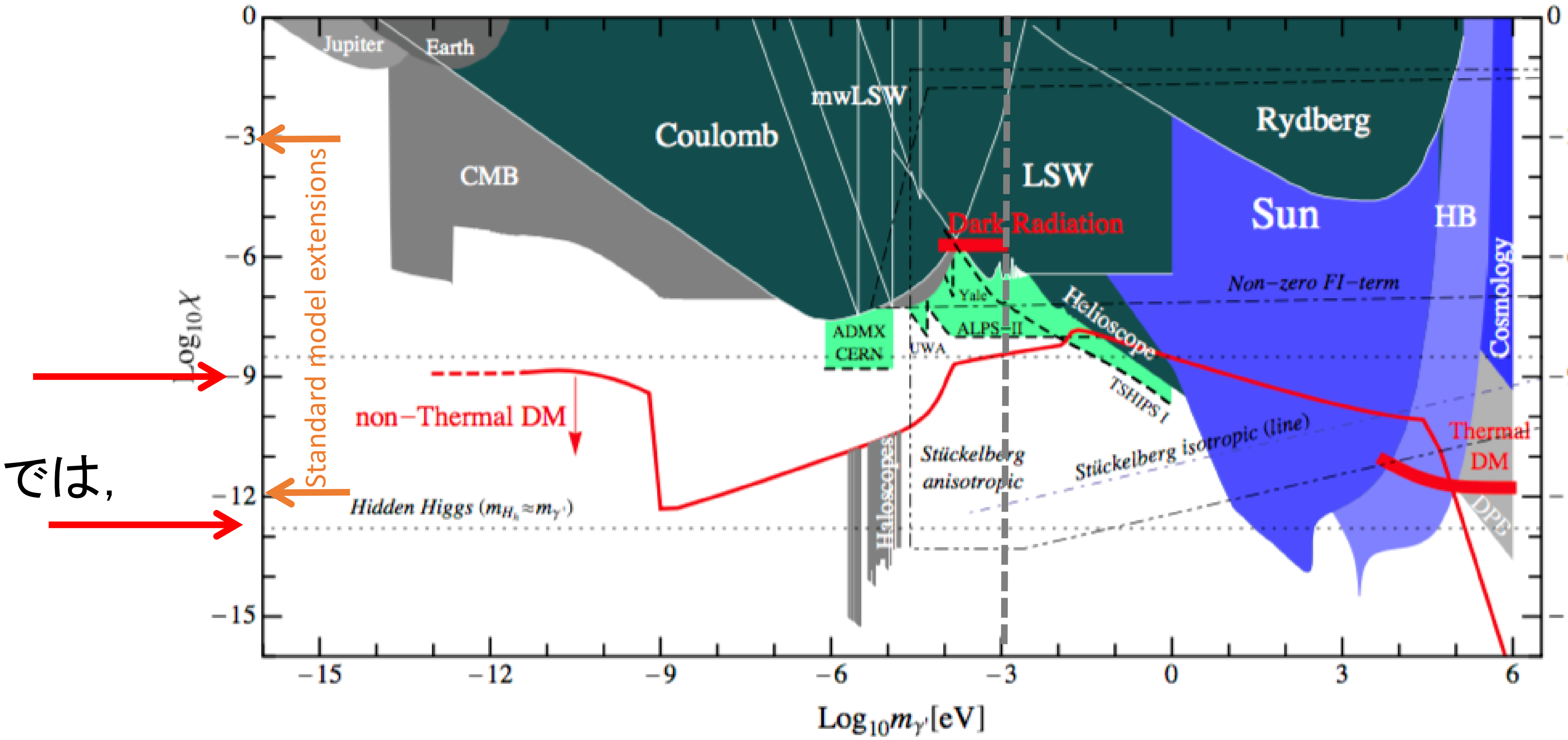
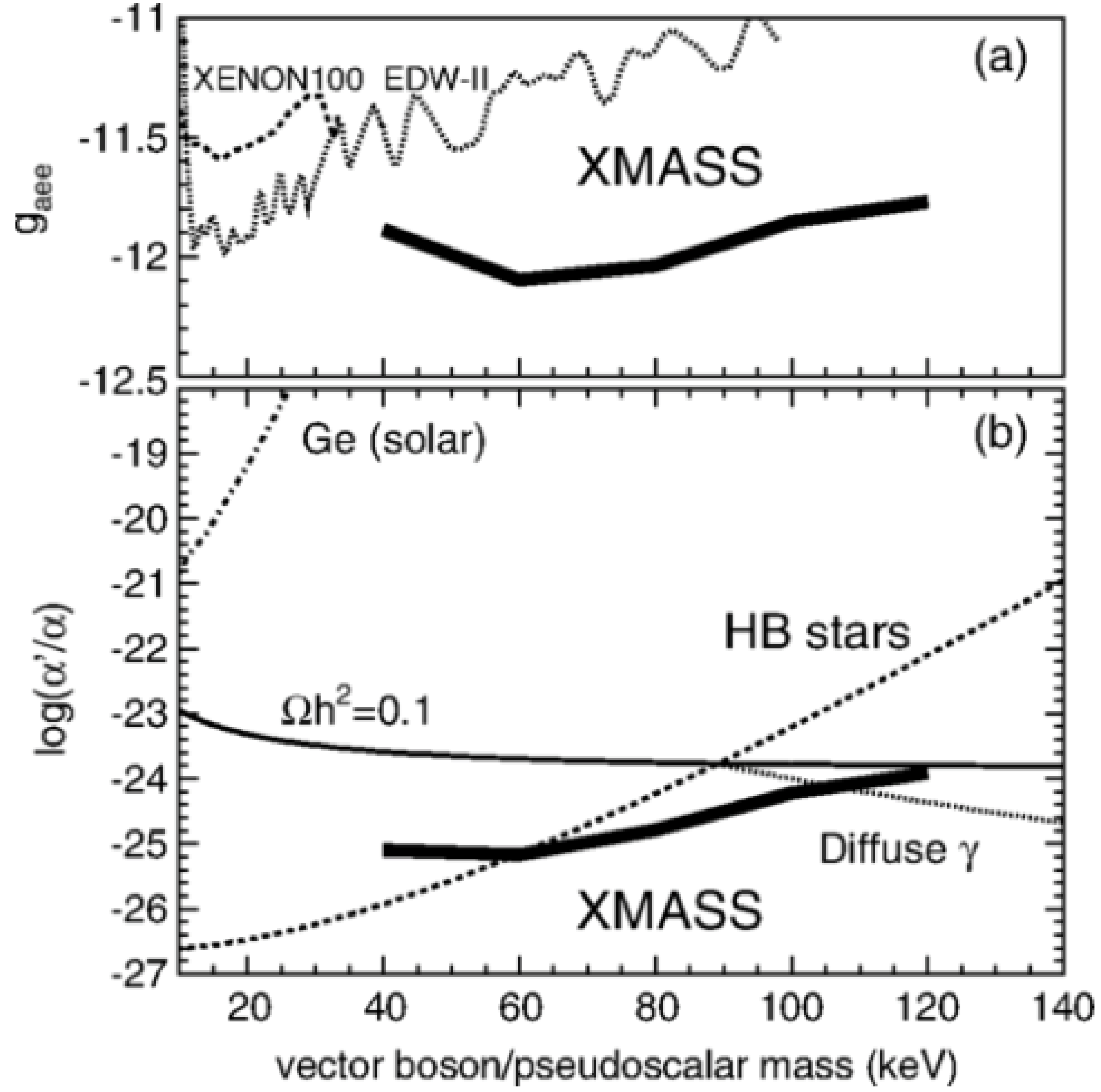


Fig. 4. Kinetic mixing parameter vs. hidden photon mass (adapted from Refs. [2,3,27]). Coloured regions are: experimental excluded regions (dark green), constraints from astronomical observations (grey) or from astrophysical or cosmologic arguments (blue), and sensitivity of planned experiments (light green). Shown in red are boundaries where the hidden photo would account for all cold dark matter produced either thermally or non-thermally by the vacuum-realignment mechanism where the hidden photon could account for the hint of dark radiation during the CMB epoch. The regions bounded by dotte lines show predictions from string theory corresponding to different possibilities for the nature of the hidden photon mas Hidden-Higgs, a Fayet-Iliopoulos term, or the Stückelberg mechanism. In general, predictions are uncertain by factors of orde one. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article



(a)
XENON100
EDW-II
XMASS
g_{aee}
-11
-11.5
-12
-12.5
(b)
Ge (solar)
HB stars
$\Omega h^2=0.1$
Diffuse γ
XMASS
$\log(\alpha'/\alpha)$
-19
-20
-21
-22
-23
-24
-25
-26
-27
20
40
60
80
100
120
140
vector boson/pseudoscalar mass (keV)

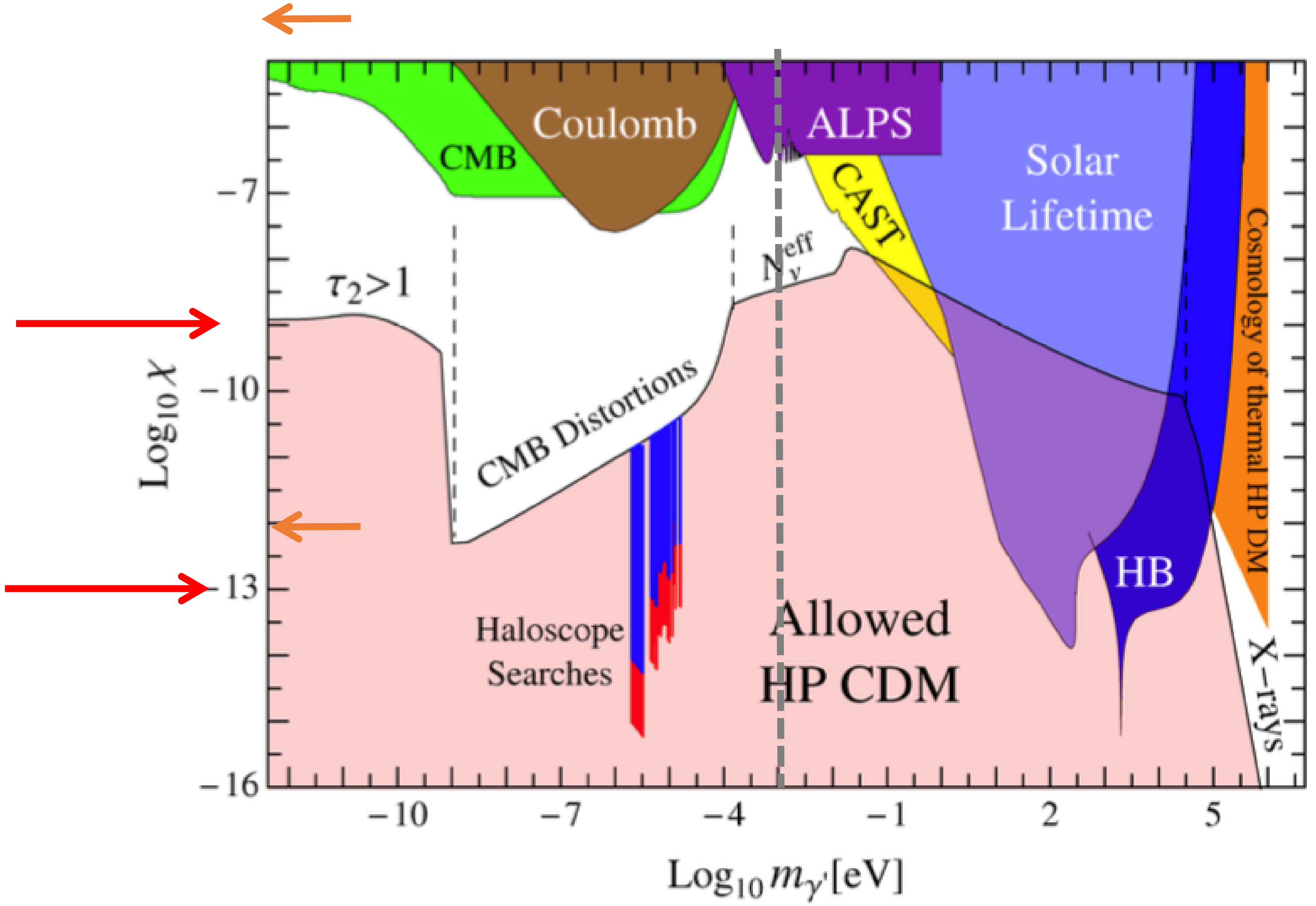


Figure 5. Allowed parameter space for hidden photon cold dark matter (HP CDM) (for details see text). The exclusion regions labelled "Coulomb", "CMB", "ALPS", "CAST" and "Solar Lifetime" arise from experiments and astrophysical observations that do not require HP dark matter (for a review see [38]). We also show constraints on the "cosmology of a thermal HP DM". Note that only constraints on HPs with masses below twice the electron mass are shown since otherwise the cosmological stability condition requires unreasonably small values of the kinetic mixing, χ. The four constraints that bound the allowed region from above, "$\tau_2 > 1$", "CMB distortions", "$N_\nu^{\rm eff}$" and "X-rays" are described in the text.

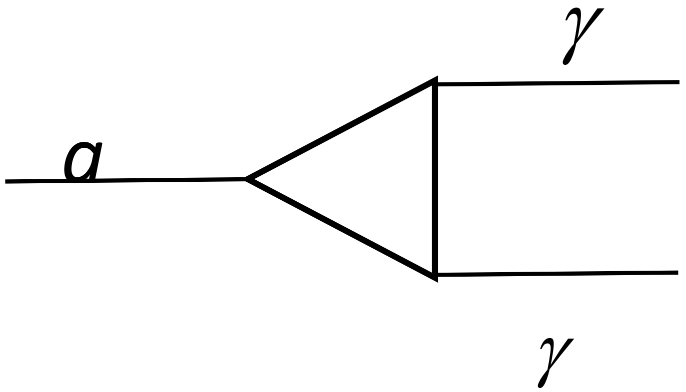
「みんな大好きアクシオン」by KEK田島

- Axion
  - Strong CP problem，θ真空，QCDアノマリー
  - $\Omega_a\, h^2 = \kappa_a \left(\frac{f_a}{10^{12}\ \mathrm{GeV}}\right)^{1.175} \ \theta_i^2$ (Misalignment production)
    - → $f_a \sim 10^{11}$ GeV or smaller, $m_a \sim 0.1$ meV <u>*or lager*</u>
  - $\Omega_a^{real} h^2 = 0.11 \left(\frac{12\ \mu\mathrm{eV}}{m_A}\right)^{1.19} \ F\Theta_i^2$
    - → $m_a \sim 10$ μeV or lower
  - Misalignment では，軽いほどたくさんできる.
    - 軽いと，宇宙がOver closeしてしまうのでCDMにならない

  - 最近重い方（1 meVとか）が好まれるようになったのは，String decayとかの寄与が計算され，その効果が主となるから.
    - 「0.1 meVがおすすめ」by ICRR川崎さん

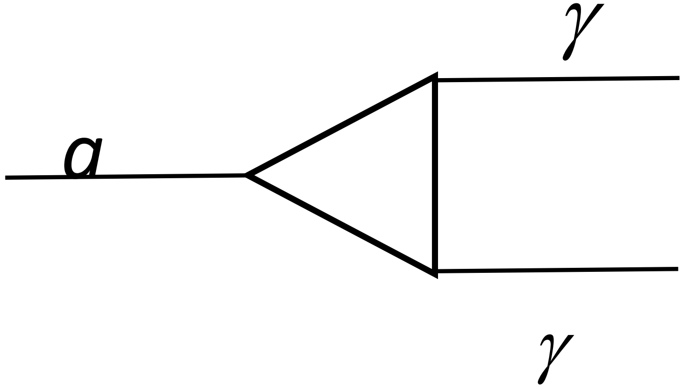
Invisible axion いろいろ

- $\mathcal{L}_{aff} = i g_f \frac{m_f}{v}\, a\, \bar{f}\gamma_5 f$
  - g_f はモデル依存
  - KSVZモデル
    - Treeでレプトンとカップルしないモデル
      - QCD由来なのでレプトンとのカップルがないのは自然に思える
  - DFSZモデル
    - Treeでレプトンともカップルするモデル
      - GUTが意識されるモデルなので，好みな人もいるかも.
      - でも，逆にa→γγでは難しい



  - この２つが特に有名
  - 不定性があり，この差が gで２桁に到達.
    - 実験的には Signal量が４桁も変わってしまう

Axion search

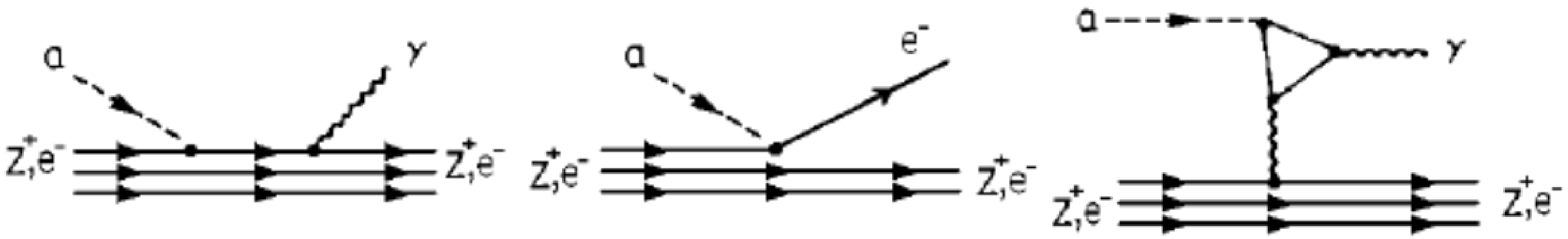


- 検出には右のPrimakov過程が一番よいとされている
  - DFSZ　　E/N=8/3
  - KSVZ　　E/N=0

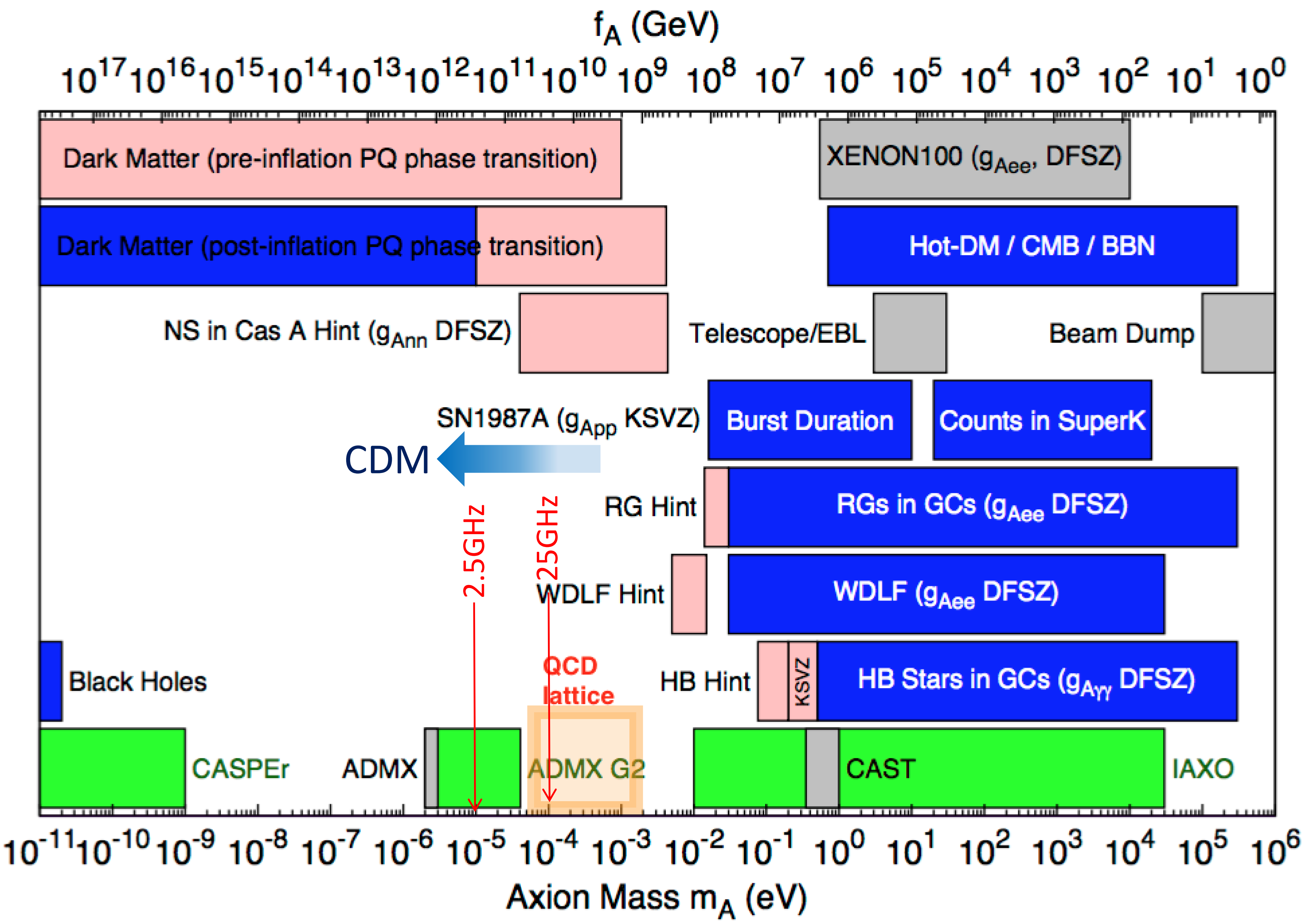
$$\mathcal{L} = -G_a \boldsymbol{E}\boldsymbol{B} a$$

$$G_a = \frac{\alpha}{2\pi}\left(\frac{E}{N} - \frac{2}{3}\frac{4+z}{1+z}\right)\frac{1+z}{z^{\frac{1}{2}}}\frac{m_a}{m_\pi f_\pi}$$

$$z = \frac{m_u}{m_d}$$

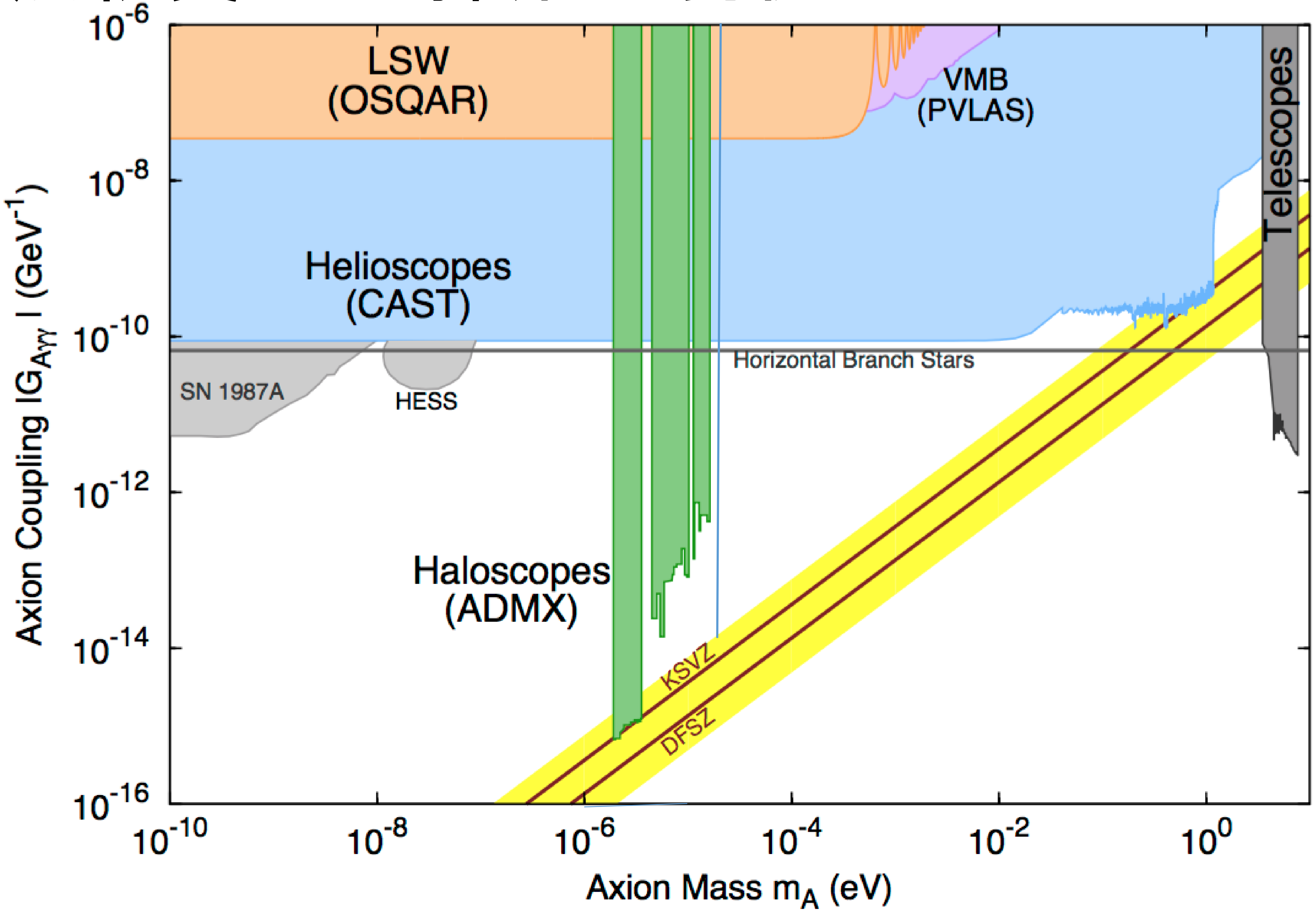


Compton-like　　Axioelectric or Photoelectric-like　　Primakoff



f_A (GeV)
10^{17} 10^{16} 10^{15} 10^{14} 10^{13} 10^{12} 10^{11} 10^{10} 10^{9} 10^{8} 10^{7} 10^{6} 10^{5} 10^{4} 10^{3} 10^{2} 10^{1} 10^{0}
Dark Matter (pre-inflation PQ phase transition)
XENON100 (g_{Aee}, DFSZ)
Dark Matter (post-inflation PQ phase transition)
Hot-DM / CMB / BBN
NS in Cas A Hint (g_{Ann} DFSZ)
Telescope/EBL
Beam Dump
SN1987A (g_{App} KSVZ)
Burst Duration
Counts in SuperK
CDM
RG Hint
RGs in GCs (g_{Aee} DFSZ)
2.5GHz
25GHz
WDLF Hint
WDLF (g_{Aee} DFSZ)
QCD lattice
Black Holes
HB Hint
KSVZ
HB Stars in GCs ($g_{A\gamma\gamma}$ DFSZ)
CASPEr
ADMX
ADMX G2
CAST
IAXO
10^{-11} 10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6}
Axion Mass m_A (eV)

暗黒物質Axion探索の現状



暗黒物質Axion実験のおさらい

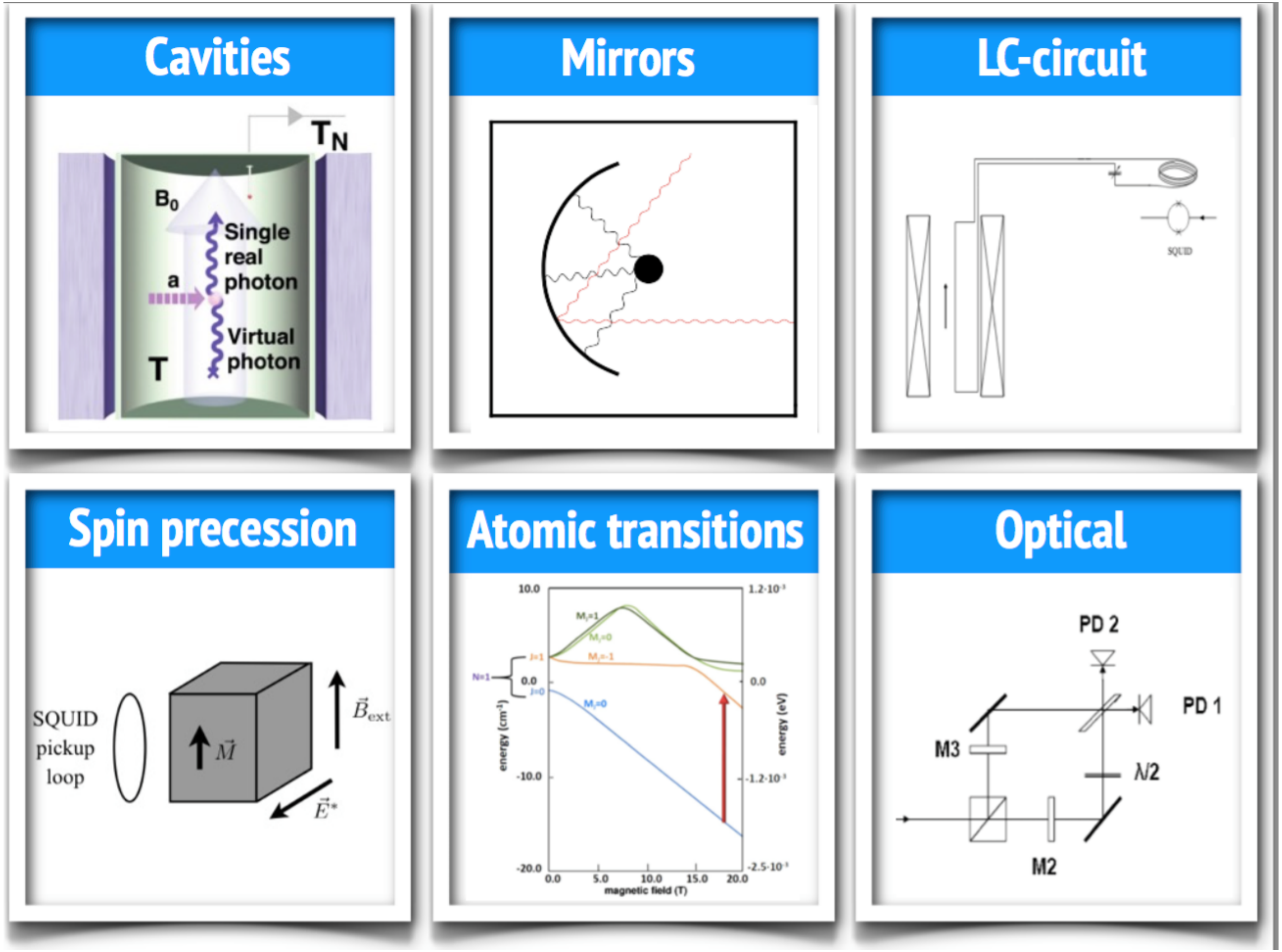
- 暗黒物質アクシオンにはマクスウェル方程式で十分

$$\nabla^2 E - \mu\epsilon\, \partial^2 E/\partial t^2 = \mu\kappa B_0\, \partial^2 a/\partial t^2 \, .$$

- 磁場の中で a→γγ を使う
  - ADMXのようなCavityを使うもの
  - MADMAXの様に表面の効果を使うもの
  - 交替磁場を使うもの

この場合，上記でεはXに依存．
そもそも，ラグランジアンから出発して，
上記の表式になるかも要確認

- どの手法であろうが，
  - 4元運動量保存
  - Axionのドブロイ波長とコヒーレント長
- に注意が必要


Cavities
T_N
B_0
Single real photon
a
Virtual photon
T
Mirrors
LC-circuit
SQUID
Spin precession
SQUID pickup loop
$\vec{M}$
$\vec{B}_{ext}$
$\vec{E}^*$
Atomic transitions
energy (cm⁻¹)
energy (eV)
magnetic field (T)
Optical
PD 2
PD 1
M3
λ/2
M2

Cavity 実験

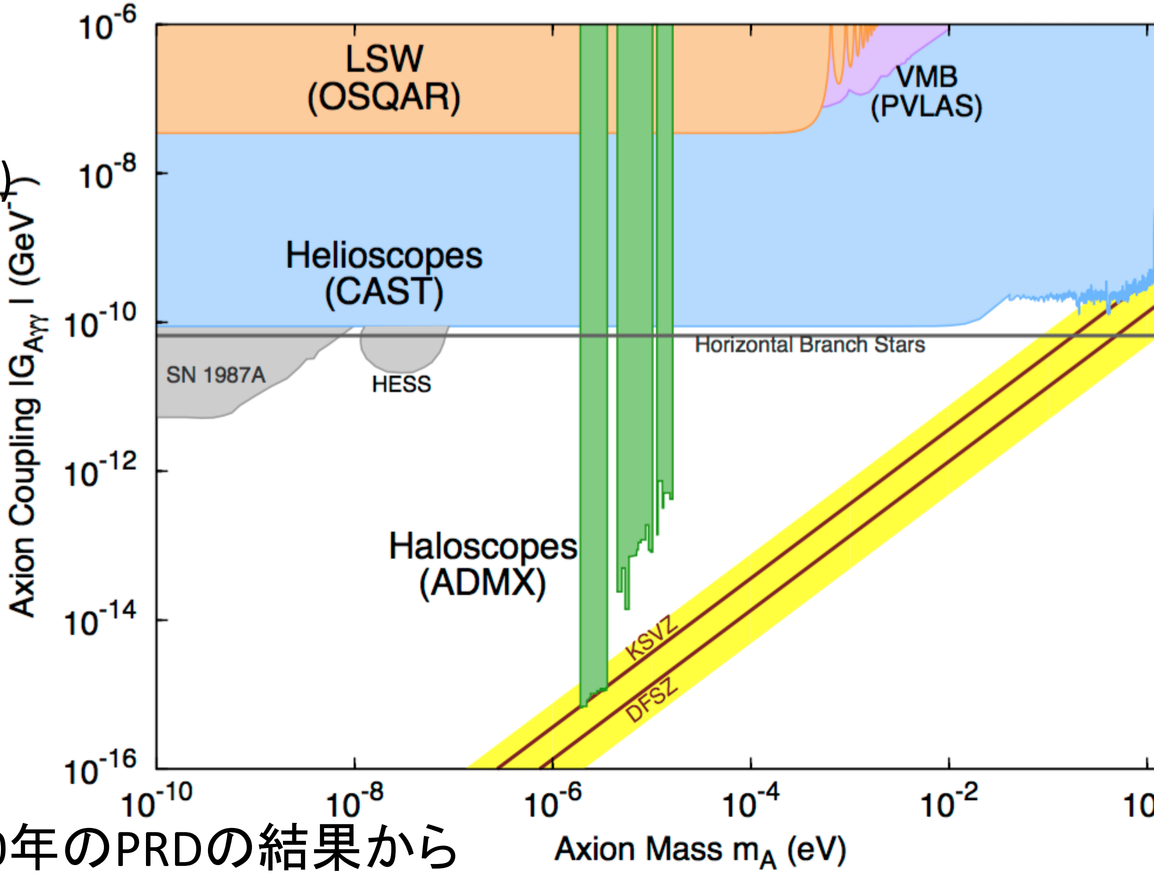
$$P_{\rm out} = \kappa g^2 V |\mathbf{B}_0|^2 \rho_0 \mathcal{G}_{\rm axion} \frac{1}{m_a} Q,$$

$$\mathcal{G}_{\rm axion} = \frac{\left(\int dV\, \mathbf{E}_{\rm cav} \cdot \mathbf{B}_0\right)^2}{|\mathbf{B}_0|^2 V \int dV\, |\mathbf{E}_{\rm cav}|^2}.$$

- 電波検出
  - 恐ろしく微弱な信号検出
  - High Qの空洞
  - 雑音と雑音そのもの
- (一様な)強磁場
- そもそもどこが狙いどころなのか？

ADMXの戦略

arXive :1405.3685 (2014)



- 高感度化
  - SQUIDの使用
  - 希釈冷凍機の導入
- 高周波数化
  - Josephson Junction 素子（JPA)の使用
    - 小テストベンチ「HEMTではダメ」1989，1990年のPRDの結果から
  - Photonic band gap cavity
  - Hyblid Super conducting cavity
  - 交代磁場の使用？

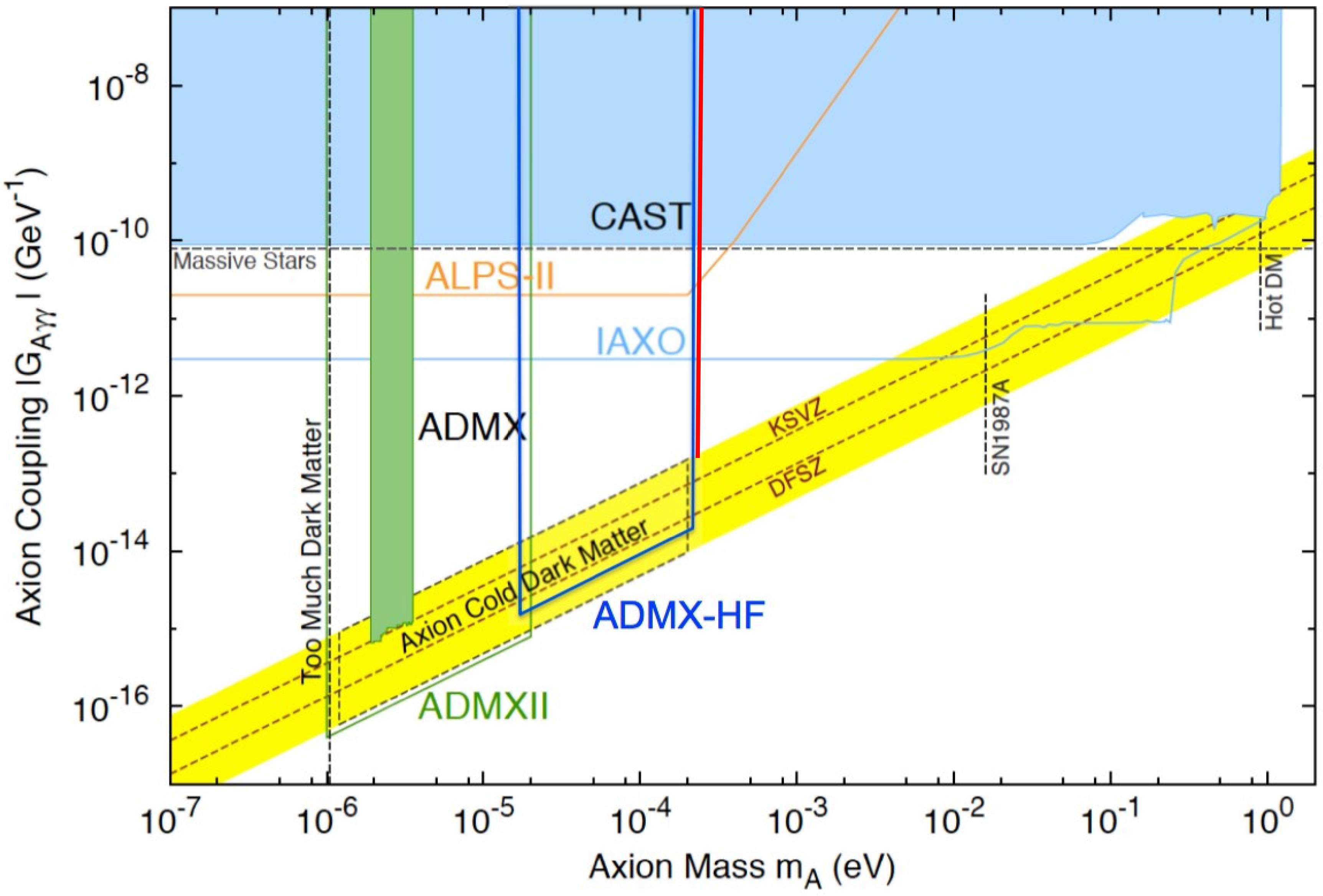


Fig. 4. The mass and coupling parameter space accessible within five years after full development of ADMX and ADMX-HF. The yellow band notionally represents the expected axion model region; shown also are the existing (CAST)[22] and proposed (IAXO)[23,24] direct solar limits, and limits achievable from the ALPS-II[25] resonant photon regeneration experiment.

arXiv:1610.02580

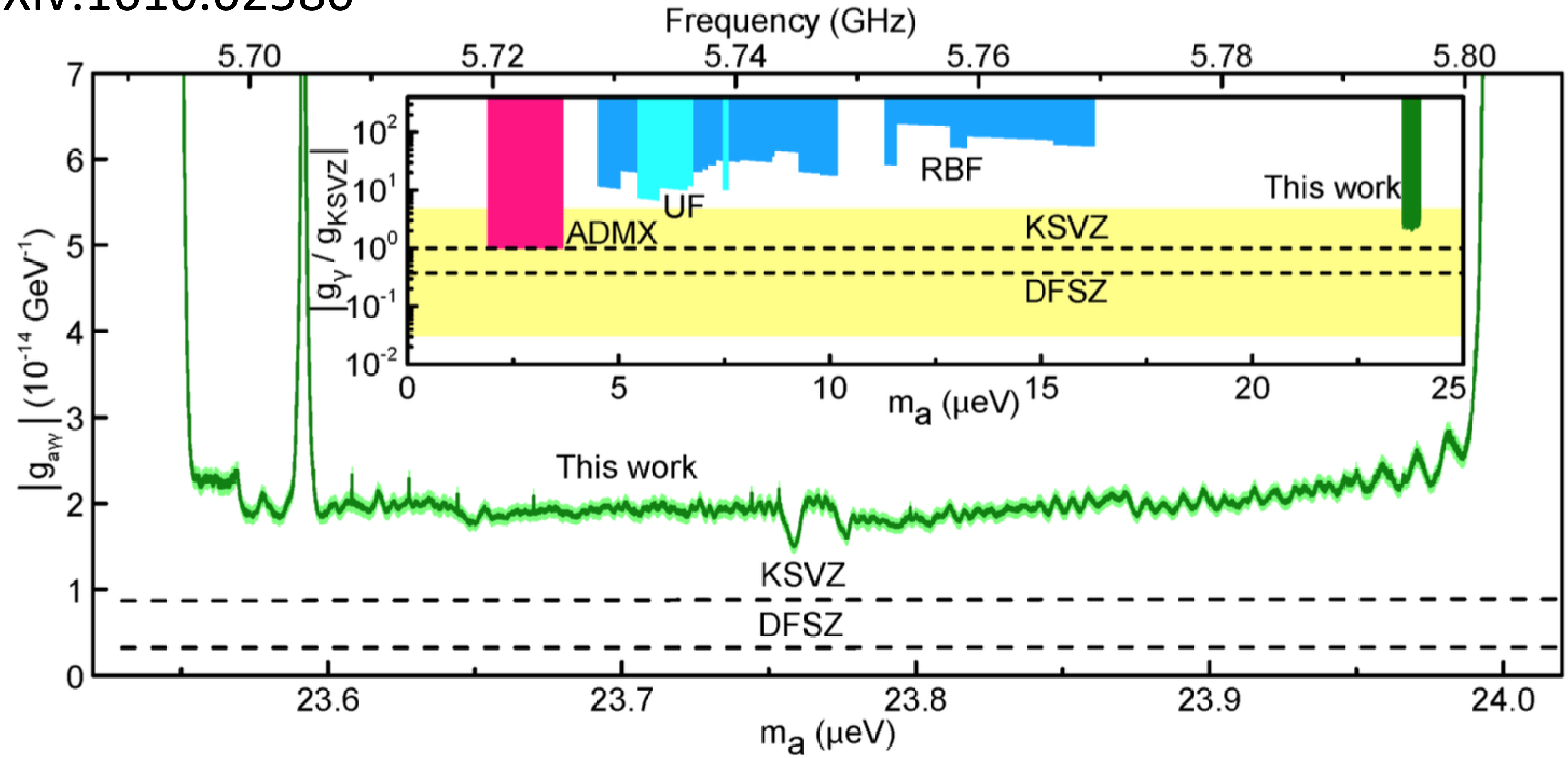
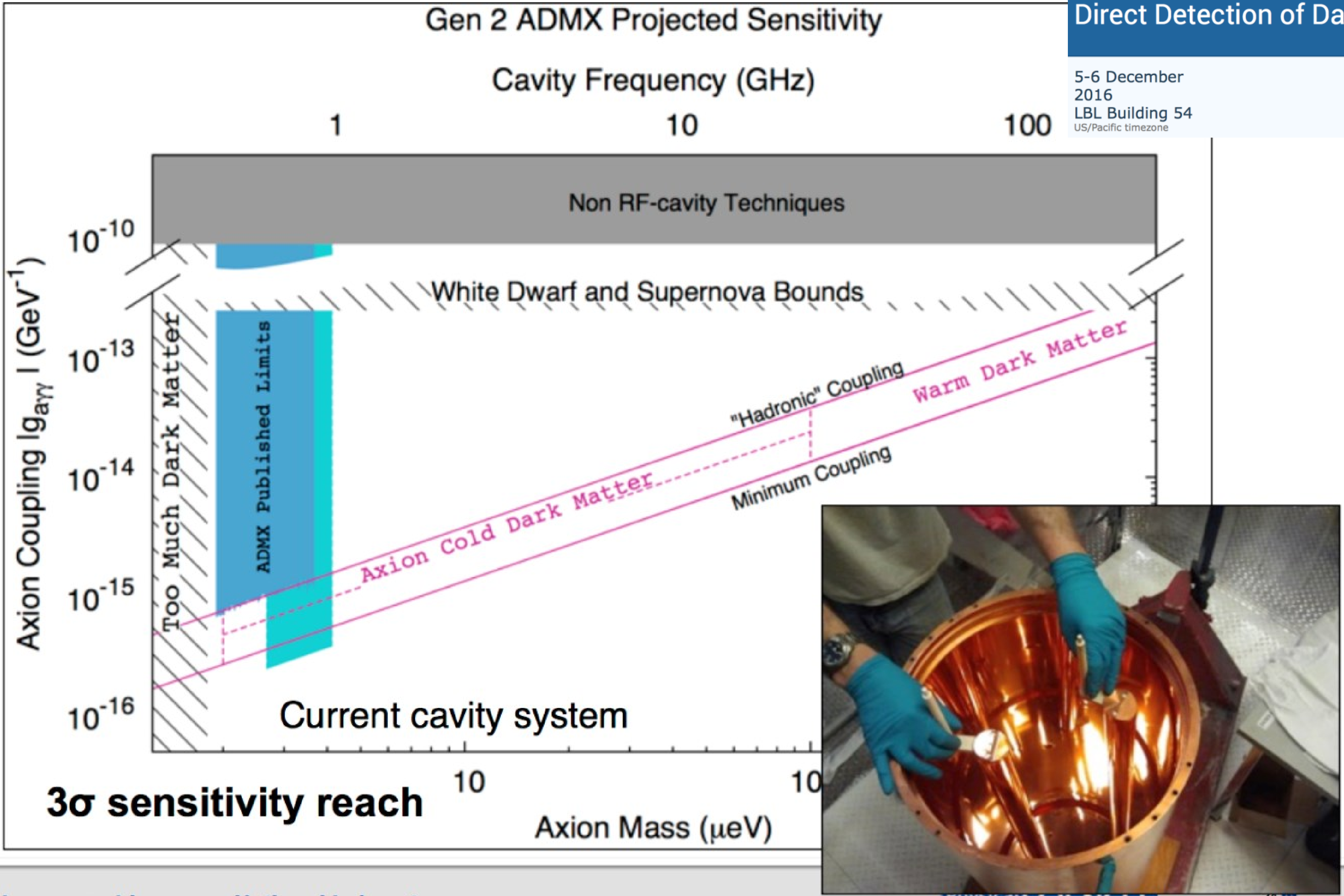


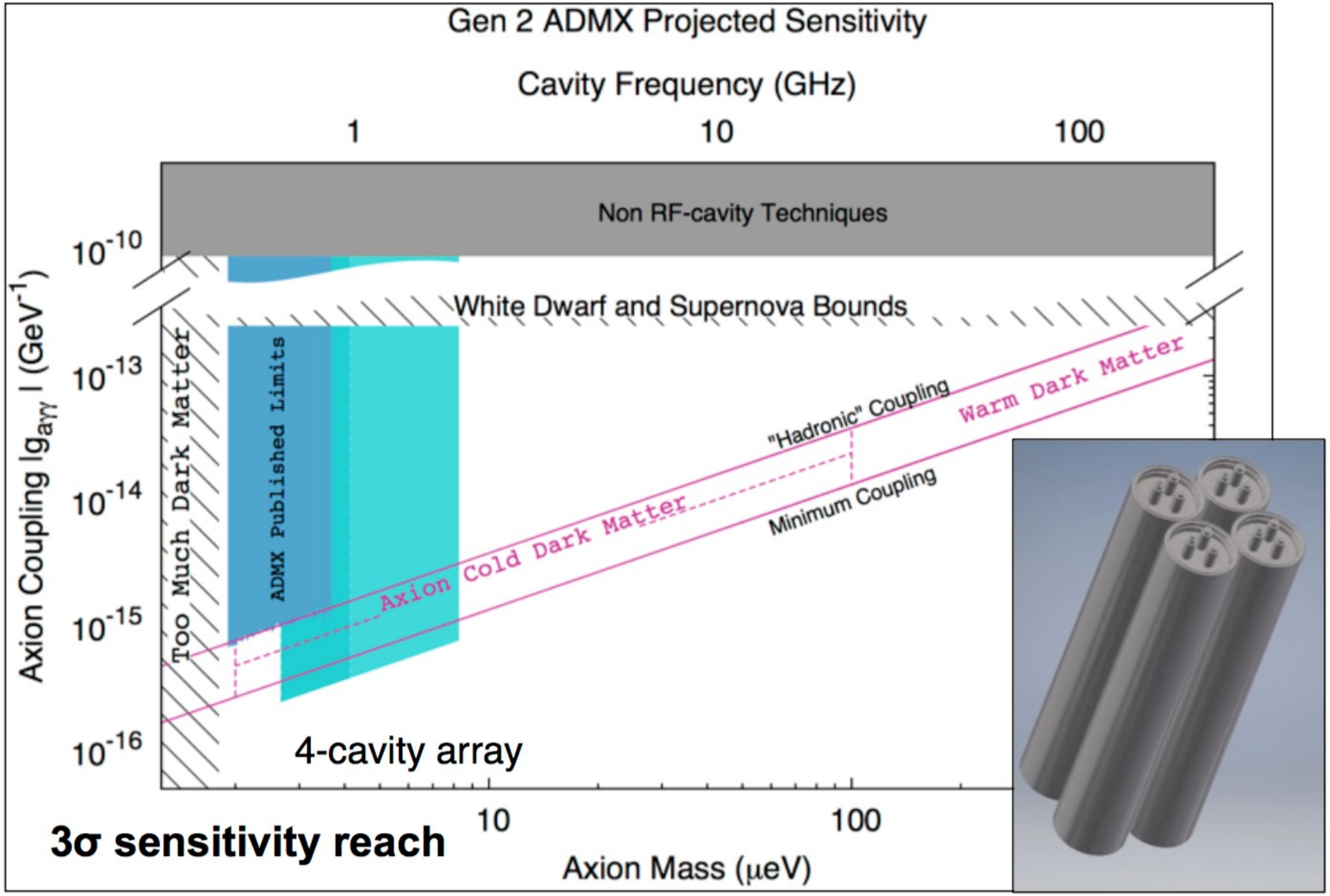
FIG. 3. Our exclusion limit at 90% confidence. The light green shaded region is a 1σ error band. The large notch around 5.704 GHz is the result of cutting spectra around a previously unidentified TE mode. The narrow notches correspond to frequencies where synthetic axion signals were injected in one of the scans. The inset shows this work (green) together with previous cavity limits from ADMX (magenta, [9]) and early experiments at Brookhaven (RBF, blue, [20]) and the University of Florida (UF, cyan, [21]). The axion model band [14] is shown in yellow.

ADMX Science Prospects: Year 1 (0.6 – 1 GHz)

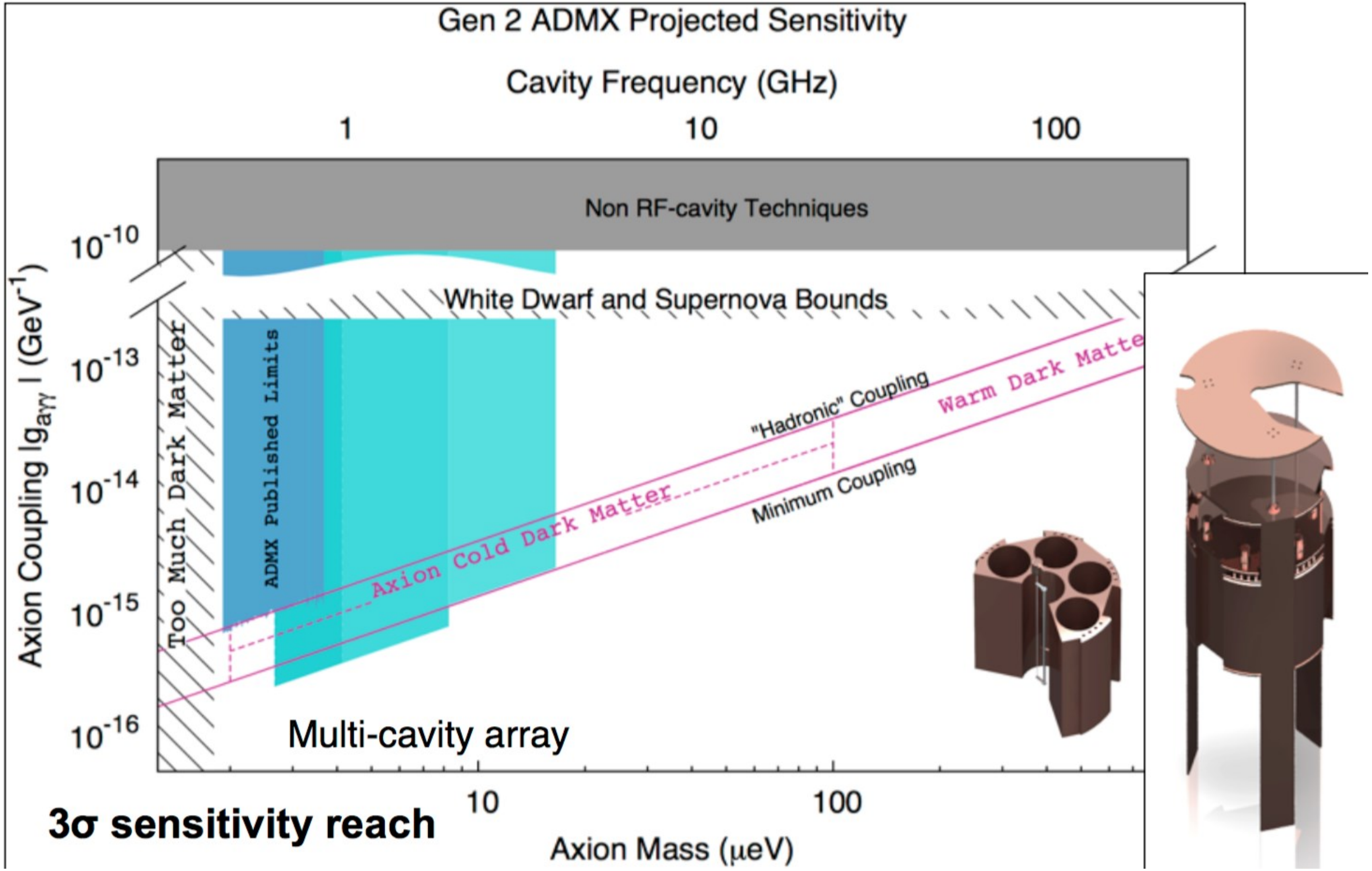
3rd Berkeley Workshop on the Direct Detection of Dark Matter
5-6 December 2016
LBL Building 54
US/Pacific timezone



ADMX Science Prospects: Year 2 (1 – 2 GHz)

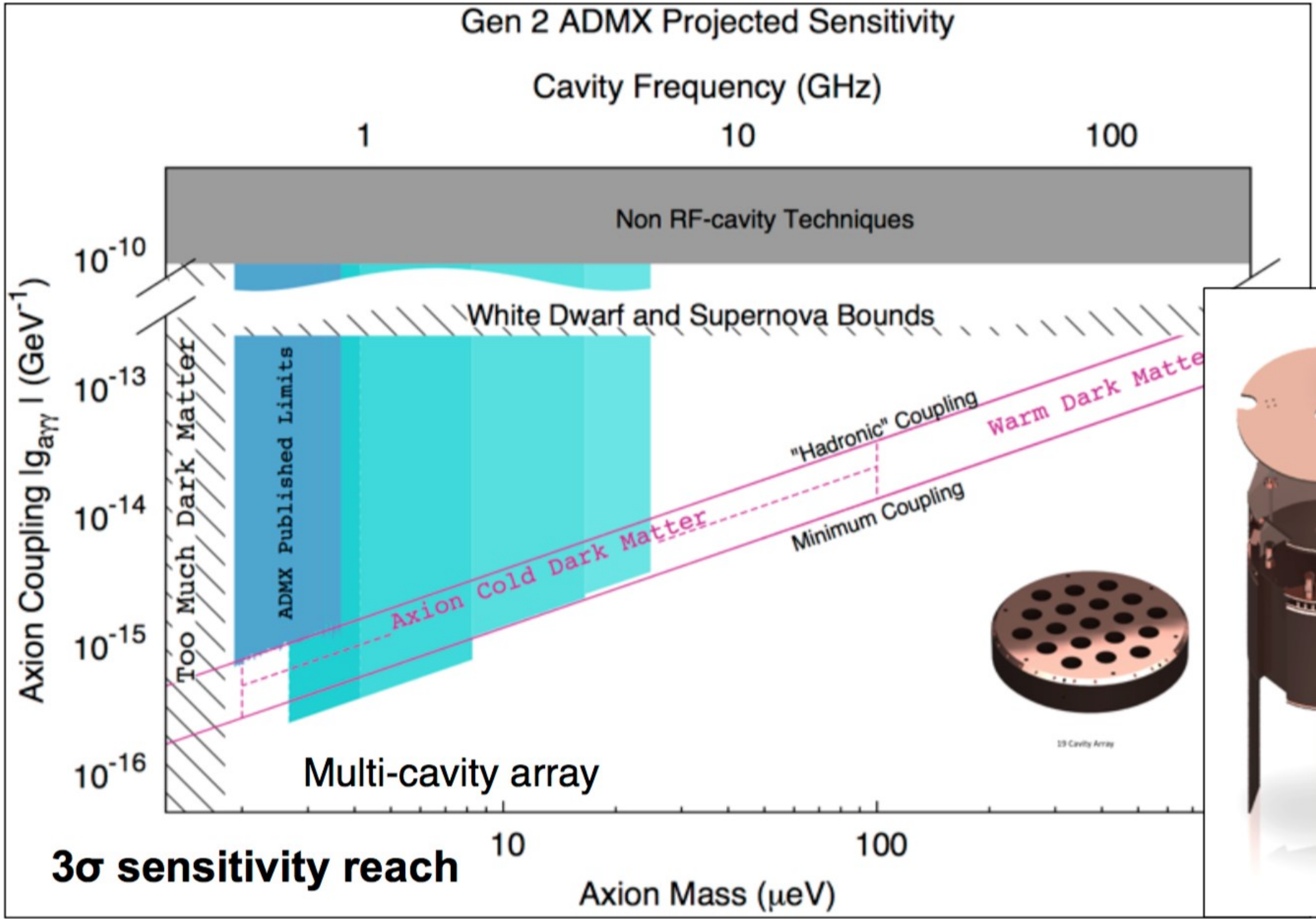


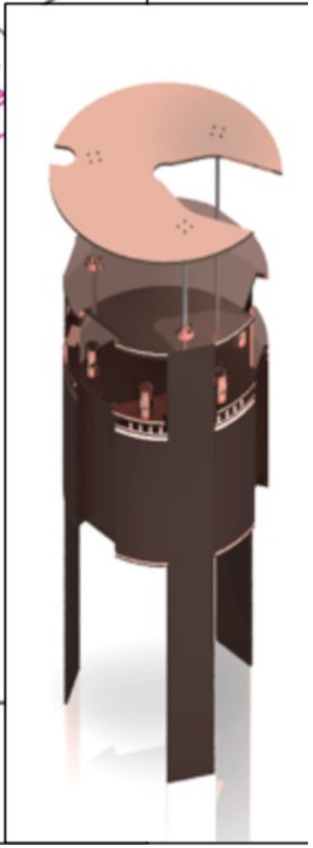
ADMX Science Prospects: Year 3 (2 – 4 GHz)



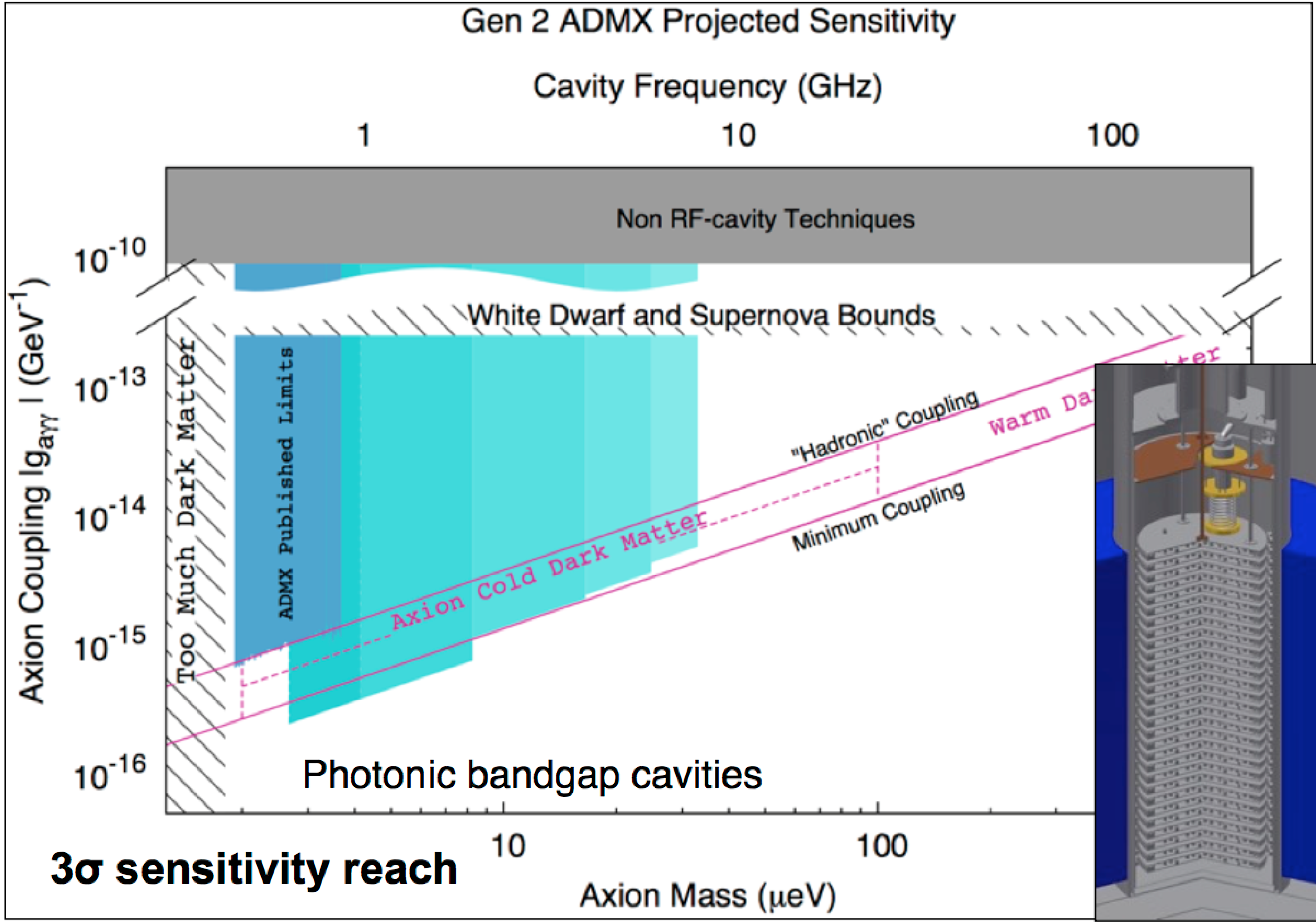
3σ sensitivity reach

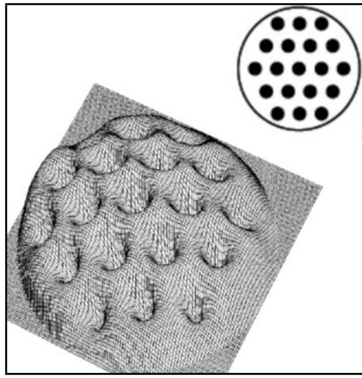
ADMX Science Prospects: Year 4 (4 – 6 GHz)



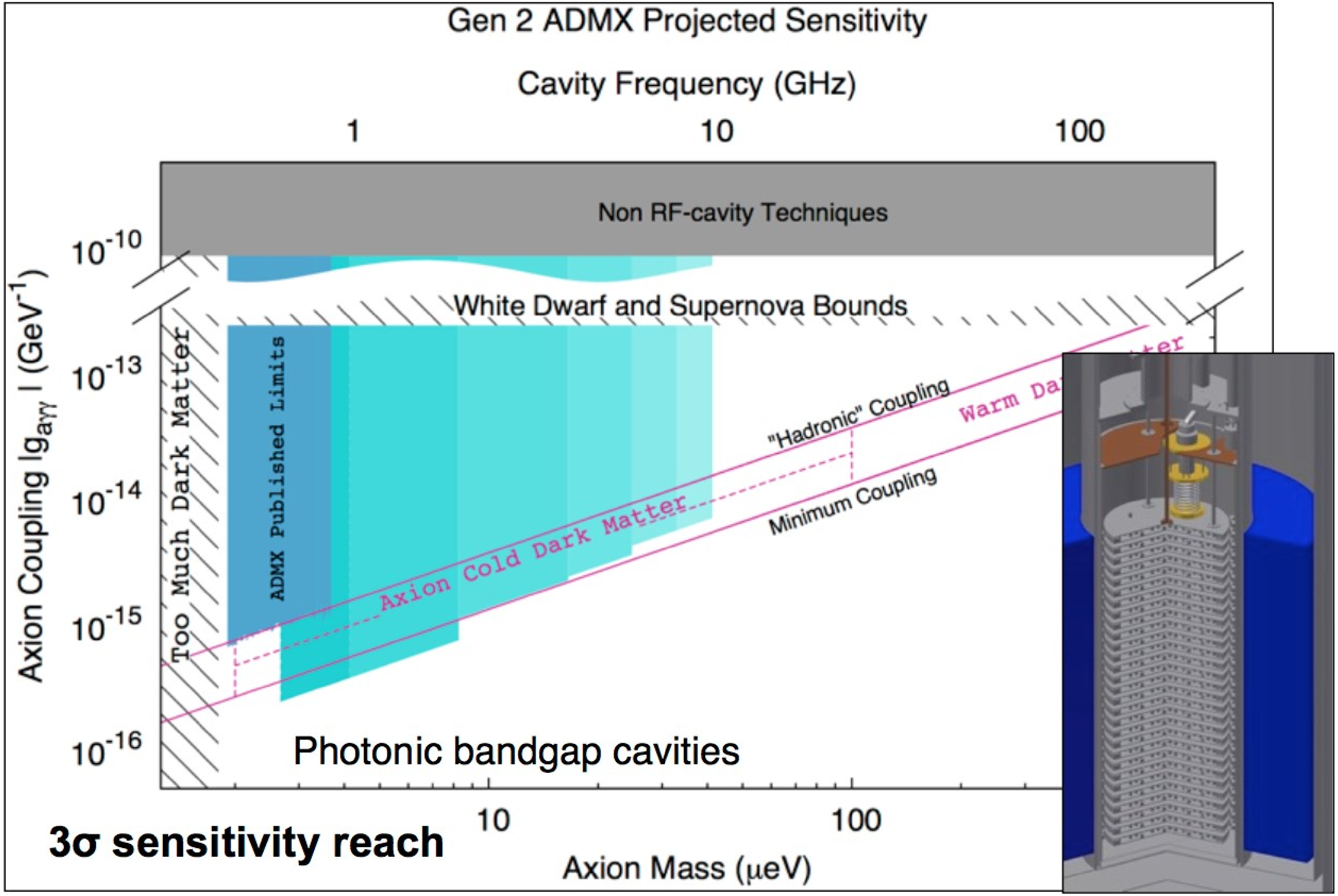


ADMX Science Prospects: Year 5 (6 – 8 GHz)

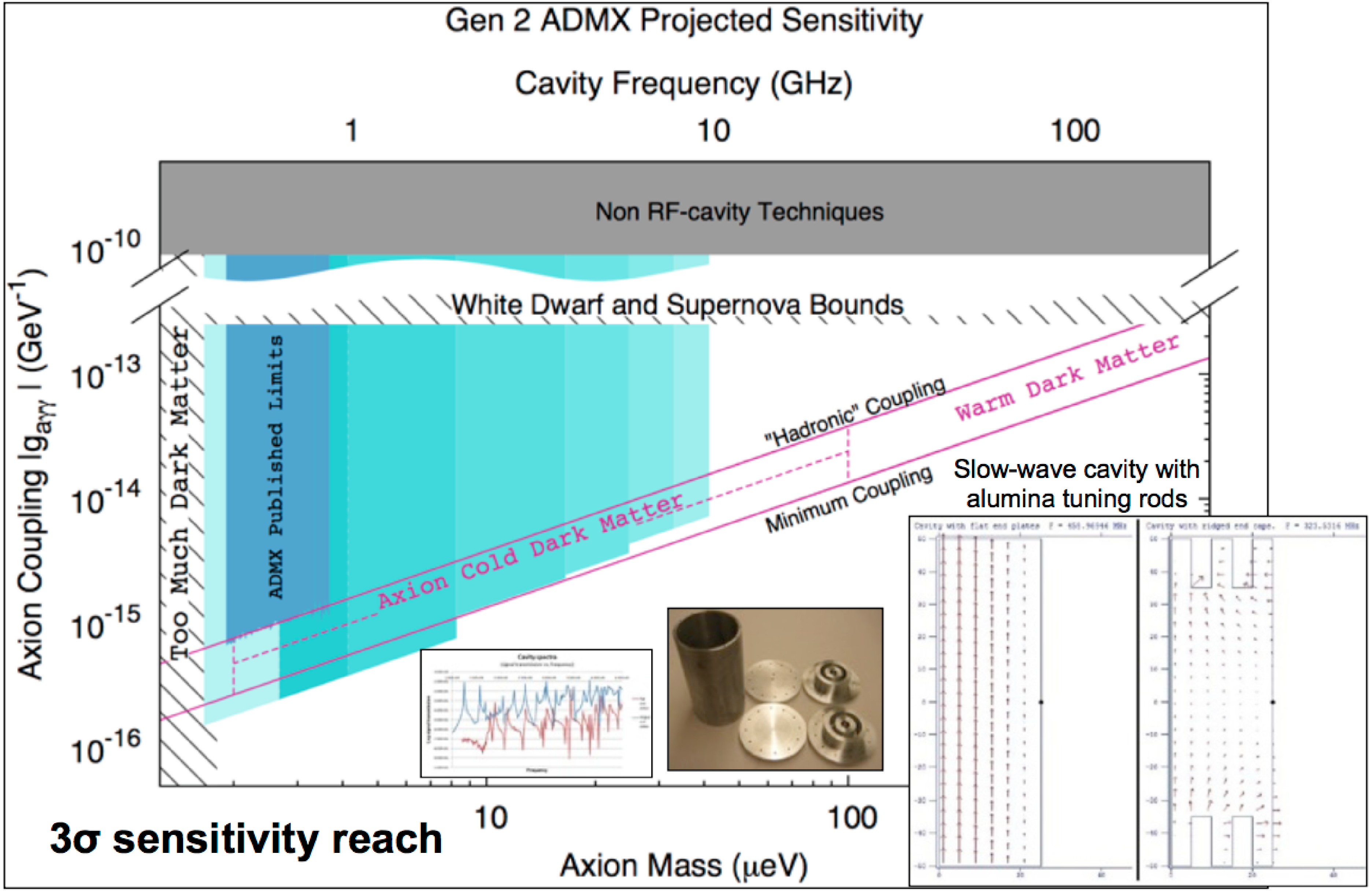




ADMX Science Prospects: Year 6 (8 – 10 GHz)

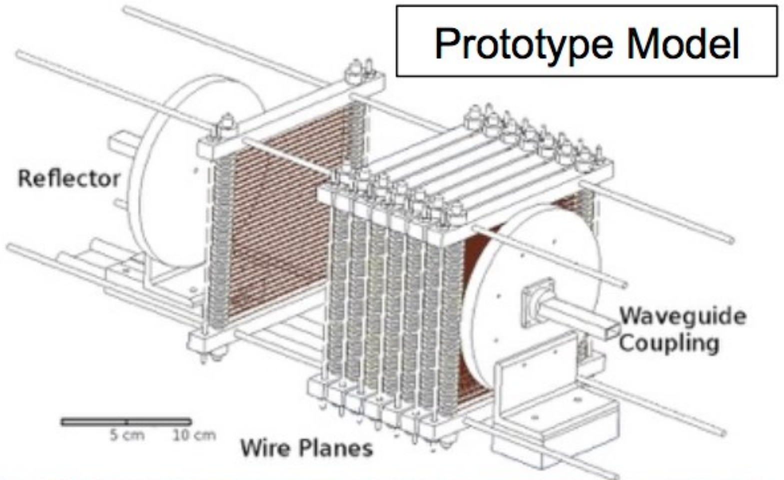


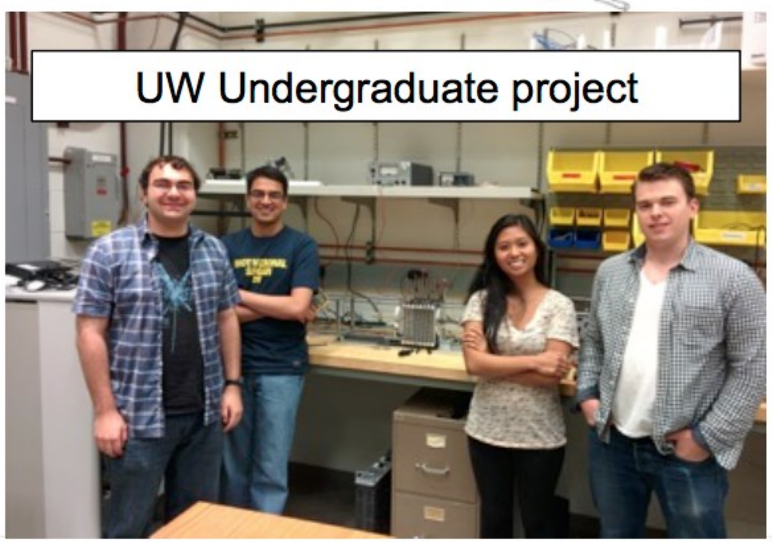
ADMX Science Prospects: Out-Years < 0.5 GHz

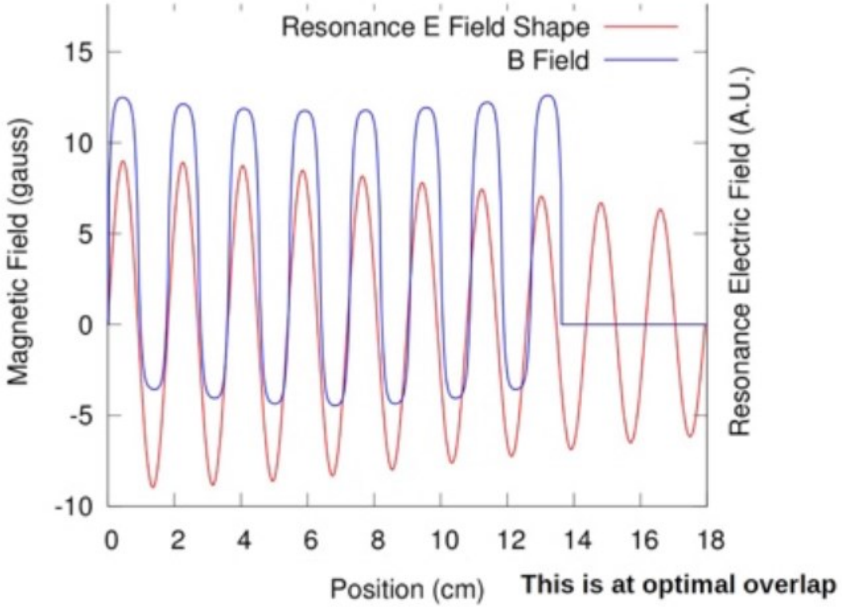


New Geometries: Open Resonator R&D

Open resonators may access frequencies too high to reach with closed cavities could expand ADMX reach to highest possible dark matter axion masses





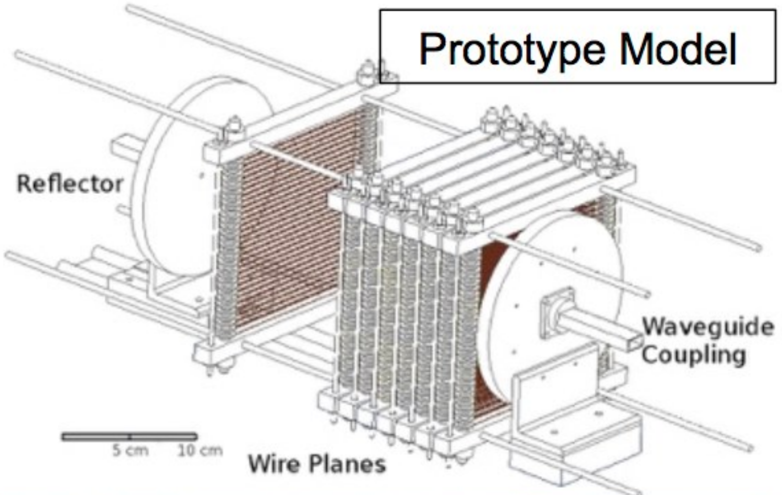


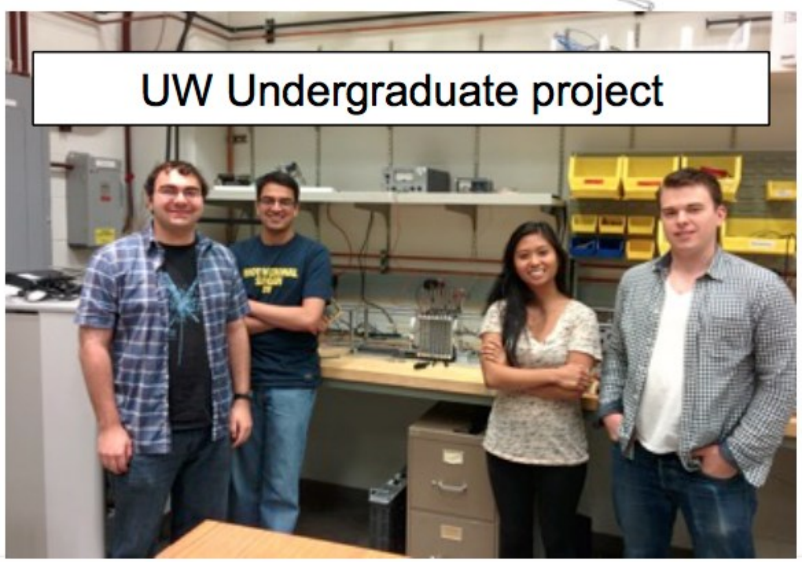
PhysRevD.91.011701

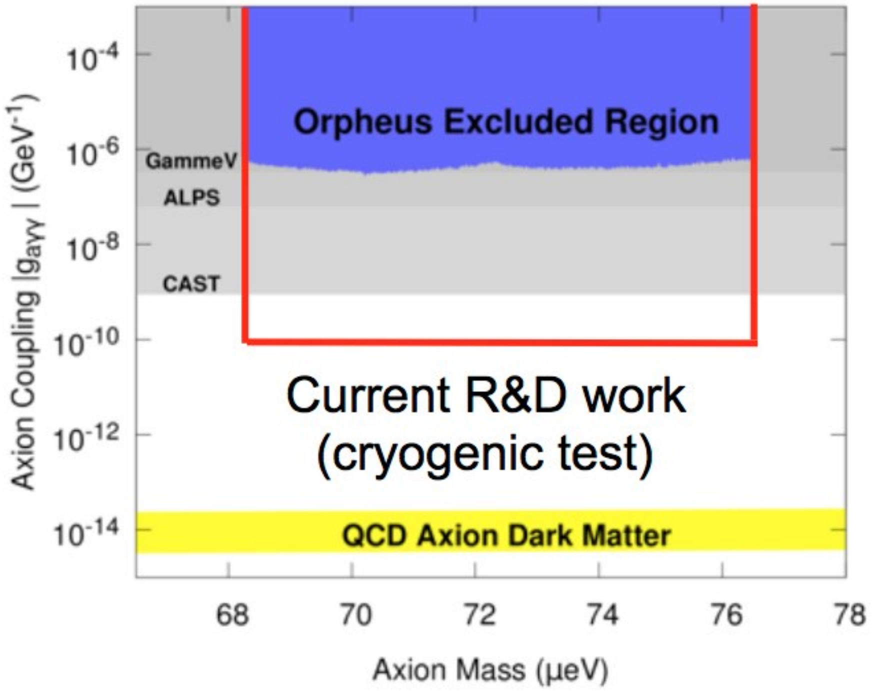
System potentially good to much higher frequencies (40 GHz or more)

Open Resonator R&D

Open resonators may access frequencies too high to reach with closed cavities could expand ADMX reach to highest possible dark matter axion masses





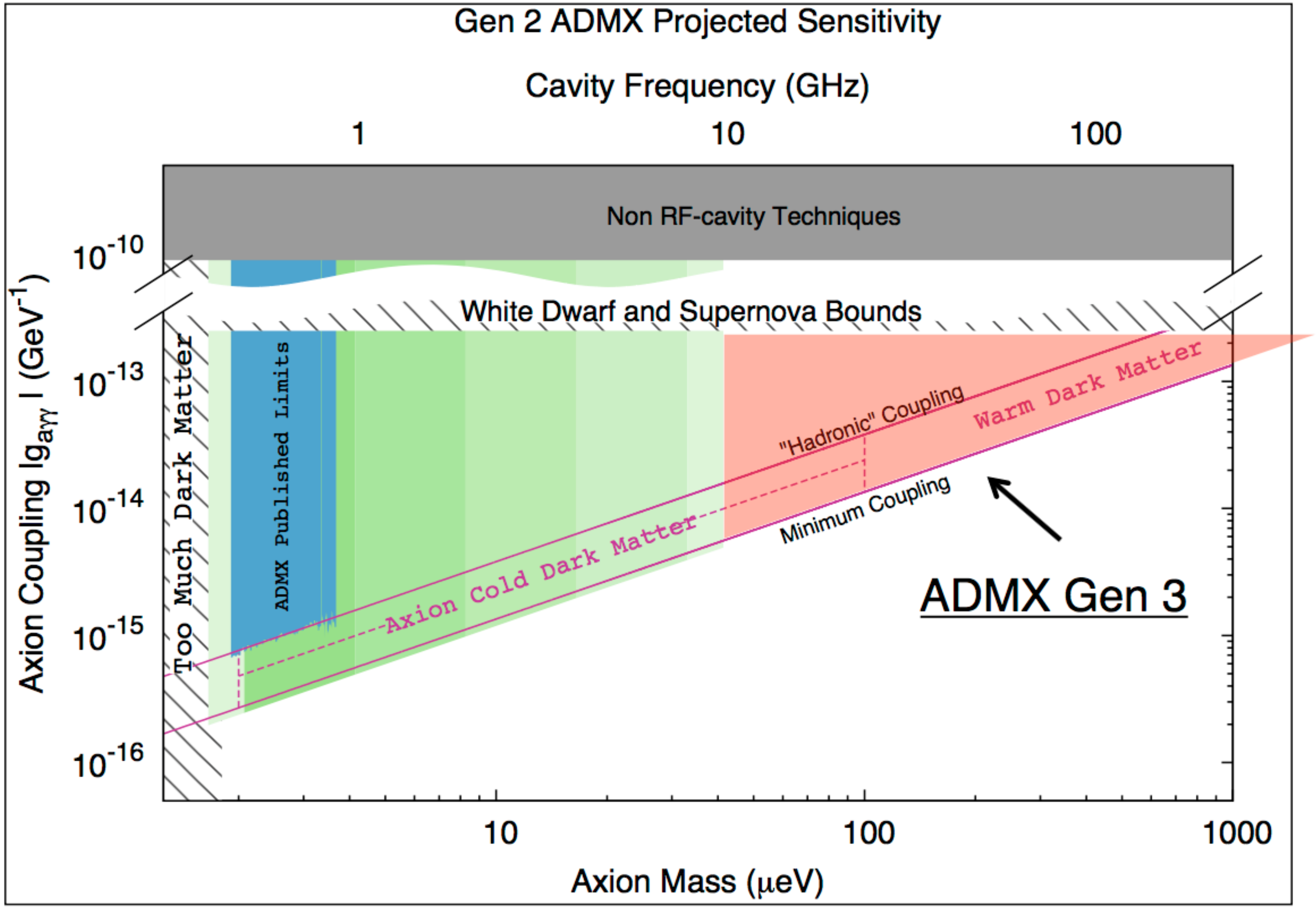


PhysRevD.91.011701

System potentially good to much higher frequencies (40 GHz or more)

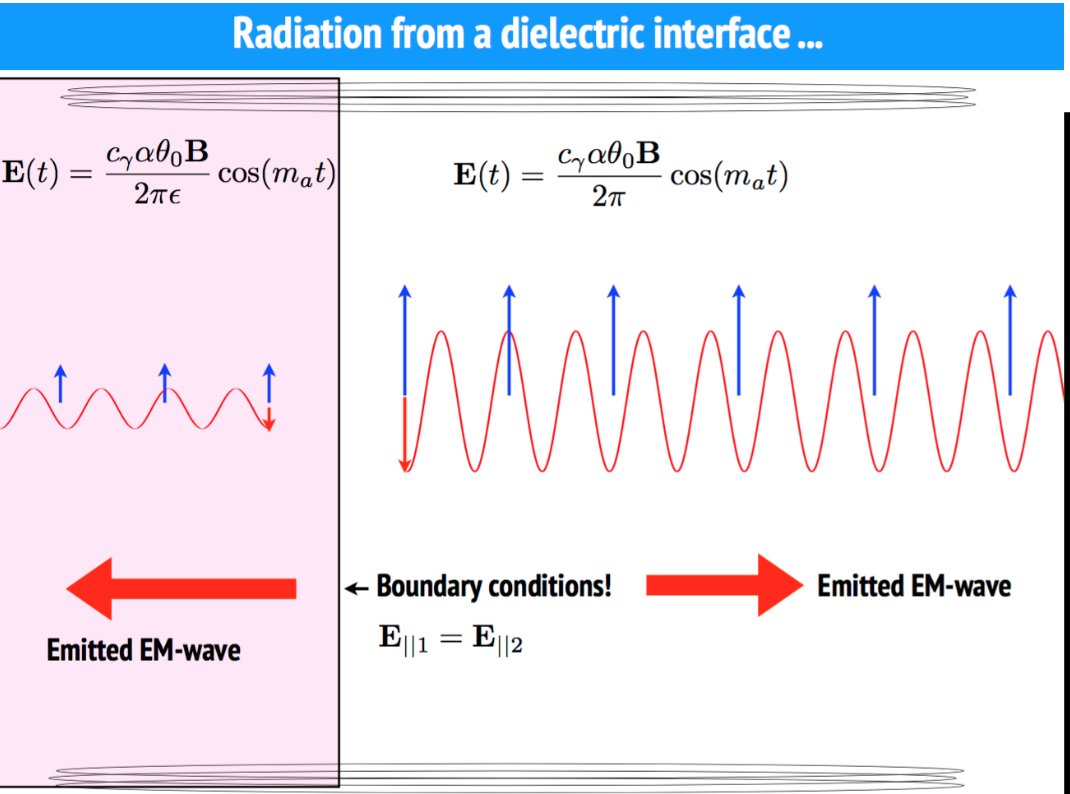
ADMX Generation 3

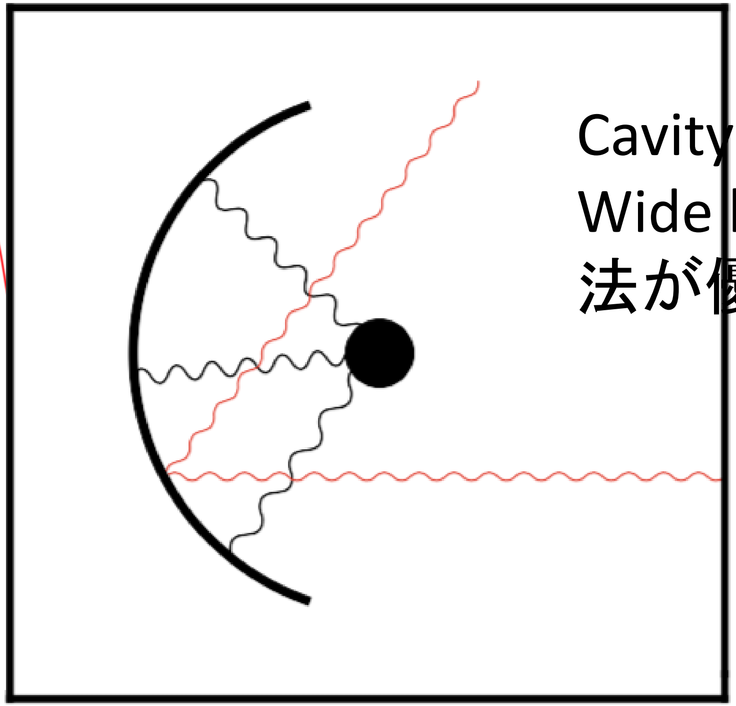
Long term goal is to <u>detect</u> or <u>rule out</u> axion as <u>primary</u> dark matter candidate.



Dish antenna

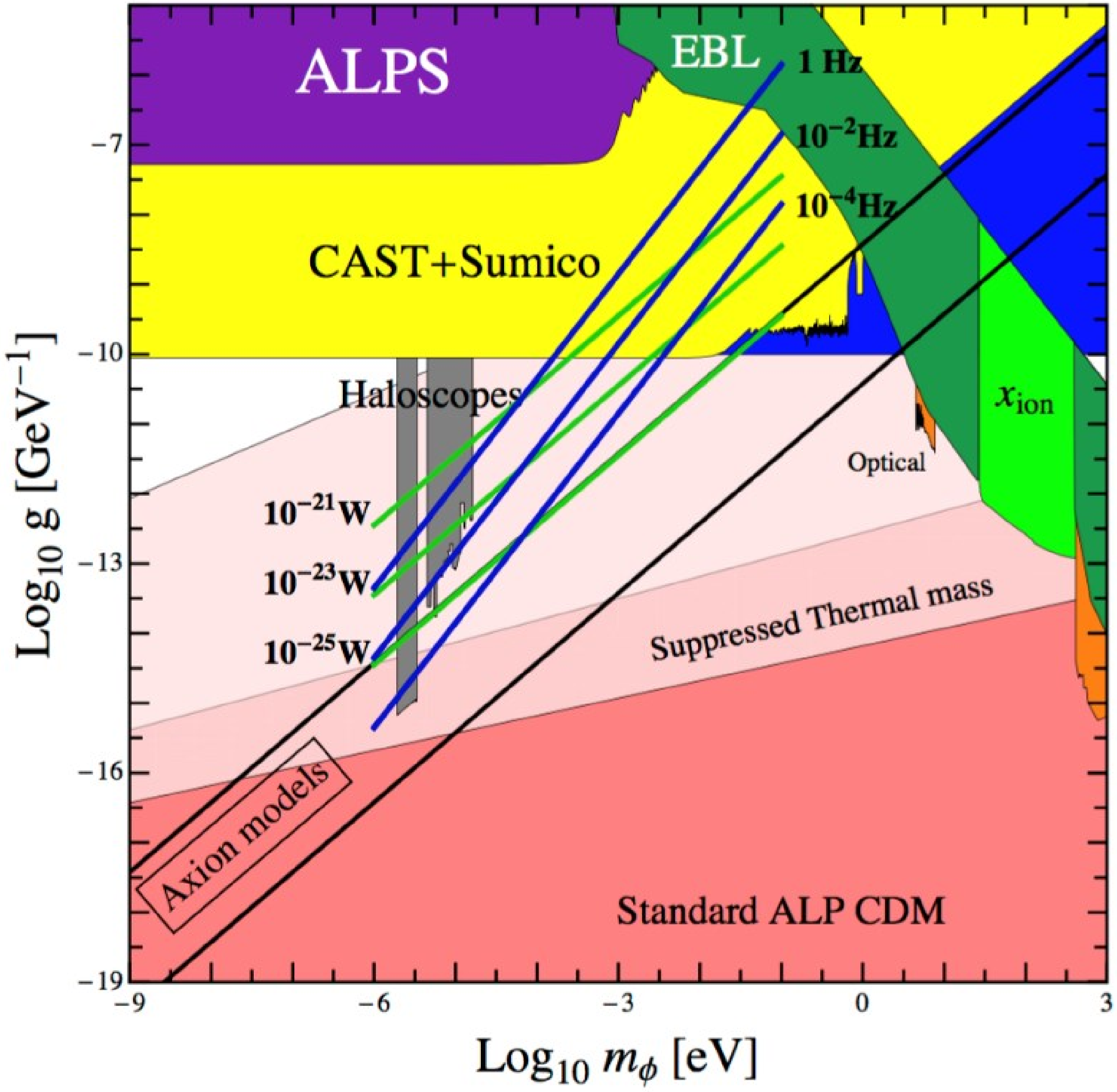
https://arxiv.org/pdf/1212.2970v1.pdf





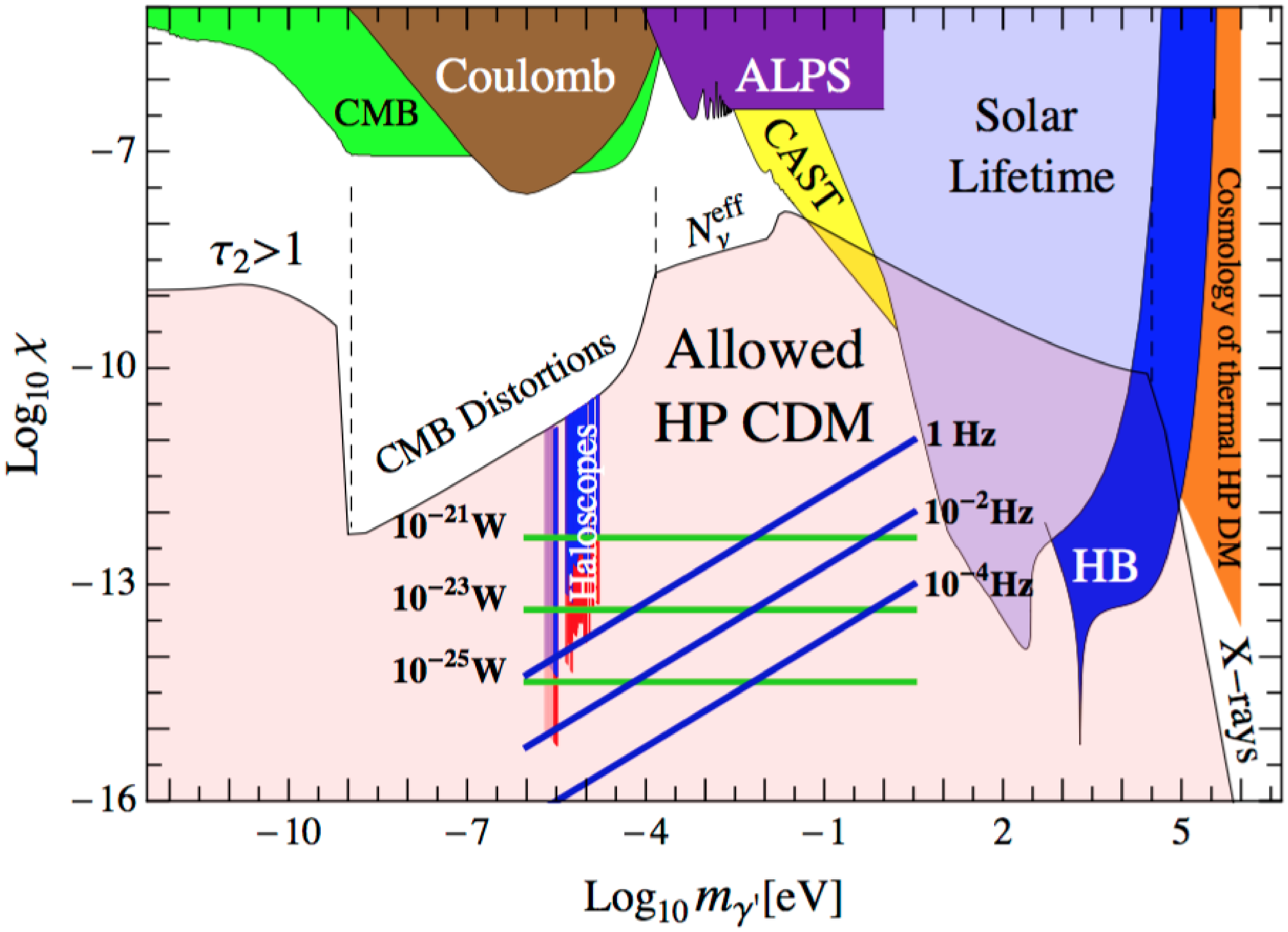
Cavityが出来ないくらい小さいとWide bandで探れる場合，この手法が優位性を持つ

Figure 2: Sketch of our WISPy cold dark matter experiment. Non relativistic HPs or ALP mixing with photons are converted into monochromatic photons (black) emitted from the surfac of an spherical dish antenna and focused in the centre, where a broadband detector is placed Photons emitted from other boundaries or from far away sources (red) are typically not focuse there.



5T, 1m²

Figure 3: The allowed parameter space for axion-like particle dark matter (ALP CDM) is shown in various shades of red (for details see Ref. [3]). The various colored regions are excluded by experiments and astrophysical observations that do not require HP dark matter (for reviews see [1,2]). The lines correspond to the sensitivity of a dish antenna (1 m^2 dish in a 5 T magnetic field) with a detector sensitive to 10^{-21}, 10^{-23} and 10^{-25} W (green, from top to bottom) and 1, 0.01 and 10^{-4} photons per second (blue, from top to bottom).



S=1m²

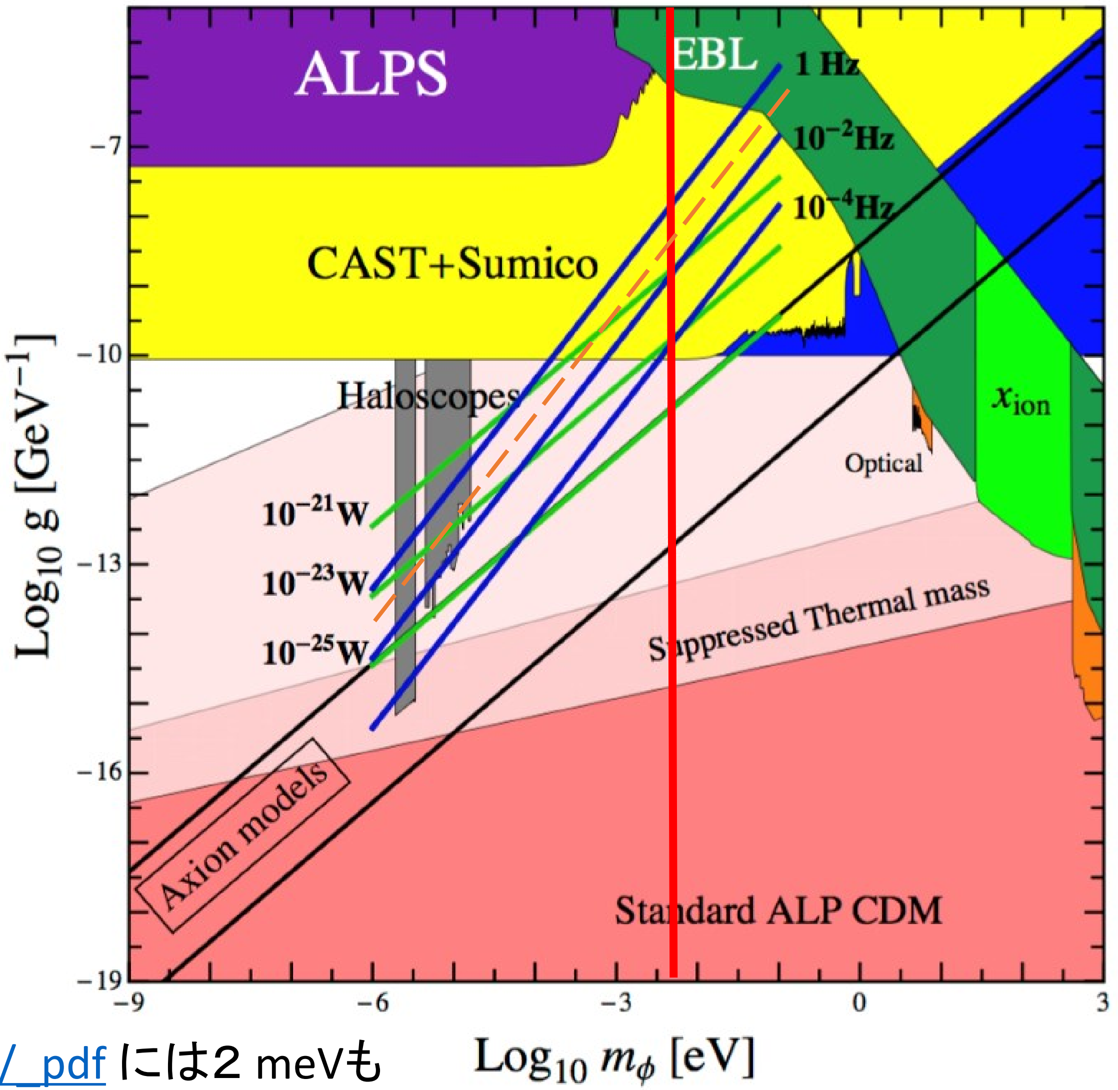
Figure 1: The allowed parameter space for hidden photon cold dark matter (HP CDM) is shown in red (for details see Ref. [3]). The regions in various colours are excluded by experiments and astrophysical observations that do not require HP dark matter (for reviews see [1,2]). The lines correspond to the sensitivity of a dish antenna ($1\,m^2$) search with a detector sensitive to 10^{-21}, 10^{-23} and 10^{-25} W (green, from top to bottom) and 1, 0.01 and 10^{-4} photons per second (blue, from top to bottom).

単一光子検出で何とかなる？

- 例: 175～210 µm (6.0~7.1 meV)（Nature, 403, P405, (200) Kimioyama）
  - Dark rate 0.001 1/s,
  - Detected photon # ~1%

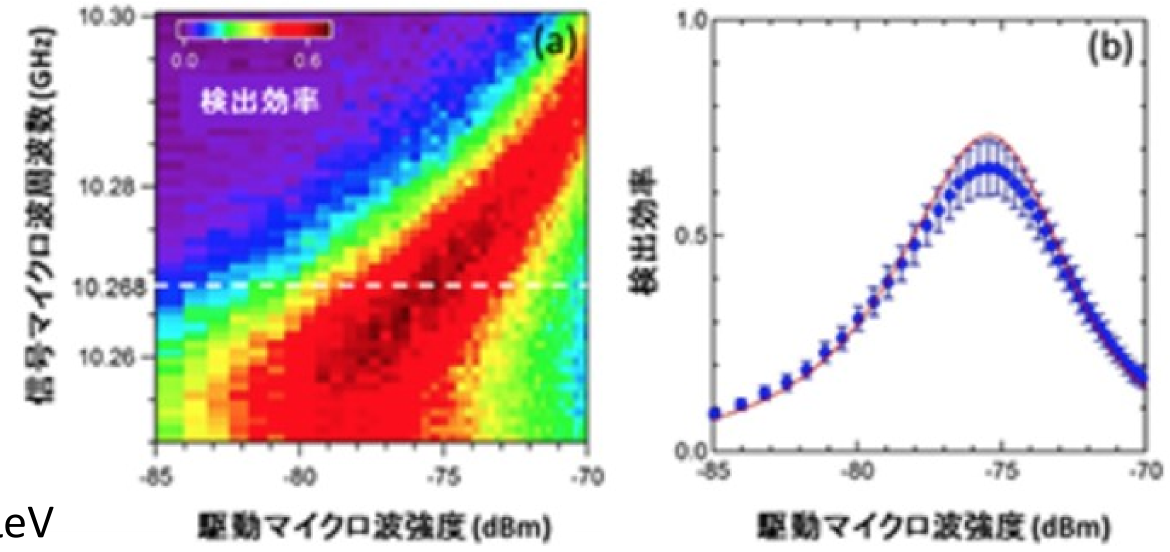
あってる？

  - NEP=10^{-22} W/√Hz



https://www.jstage.jst.go.jp/article/biophys/46/1/46_1_41/_pdf には2 meVも

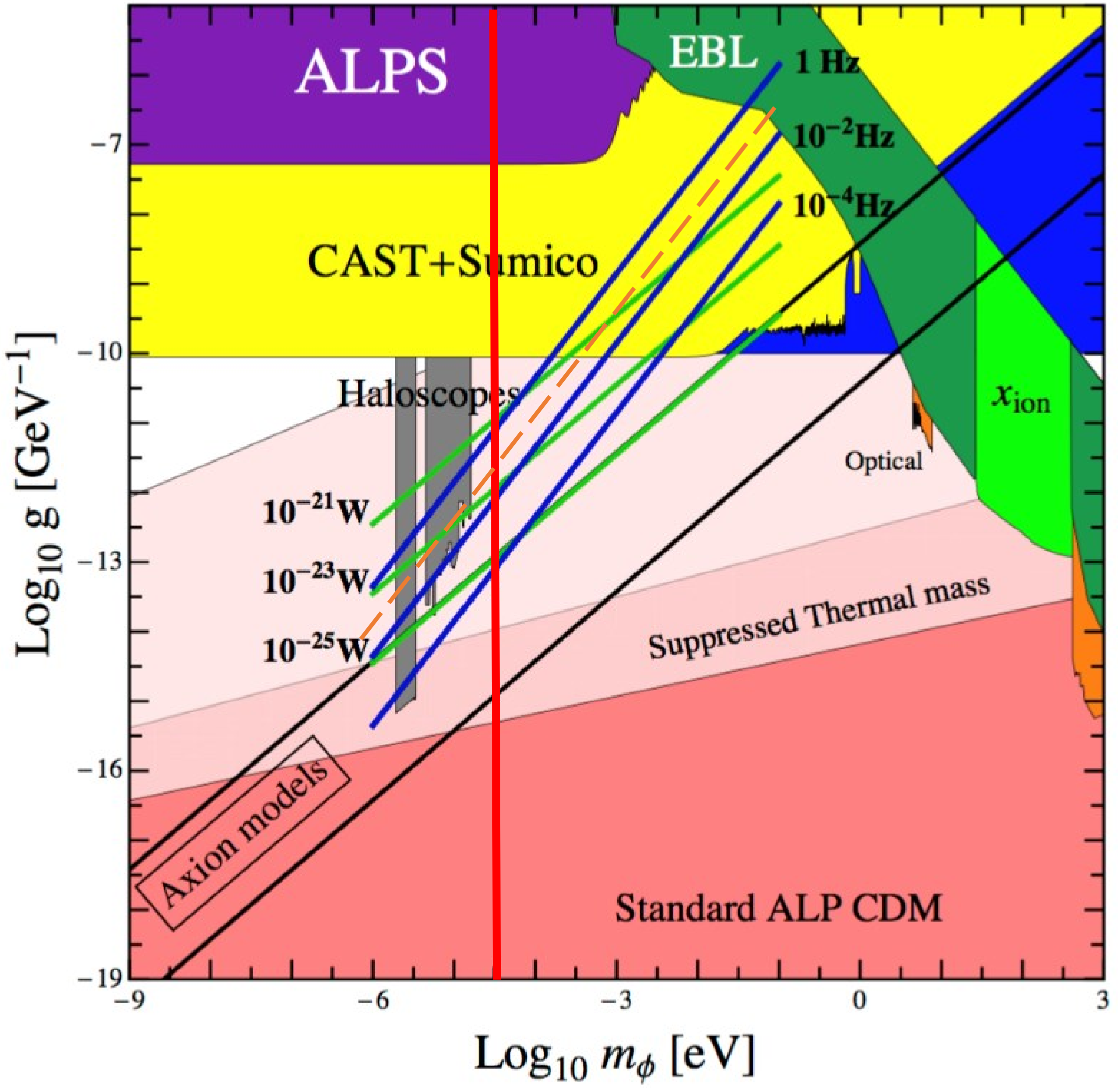
- 理研 猪俣他 (2016)
- Dark count 0.014+/-0.001
- Photon detection 0.66+/- 0.01



42 μeV

マイクロ波単一光子の検出効率

http://www.nature.com/articles/ncomms12303



- 他にも単一光子検出器は存在
  - Phys. Lev. Let. 99, 206804 (2007)

7.35 GHz=30 μeV

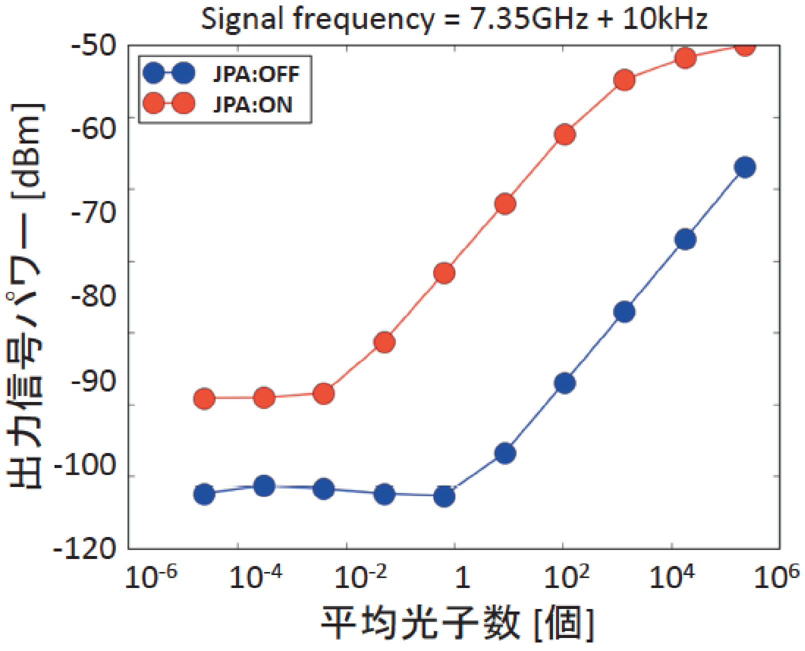
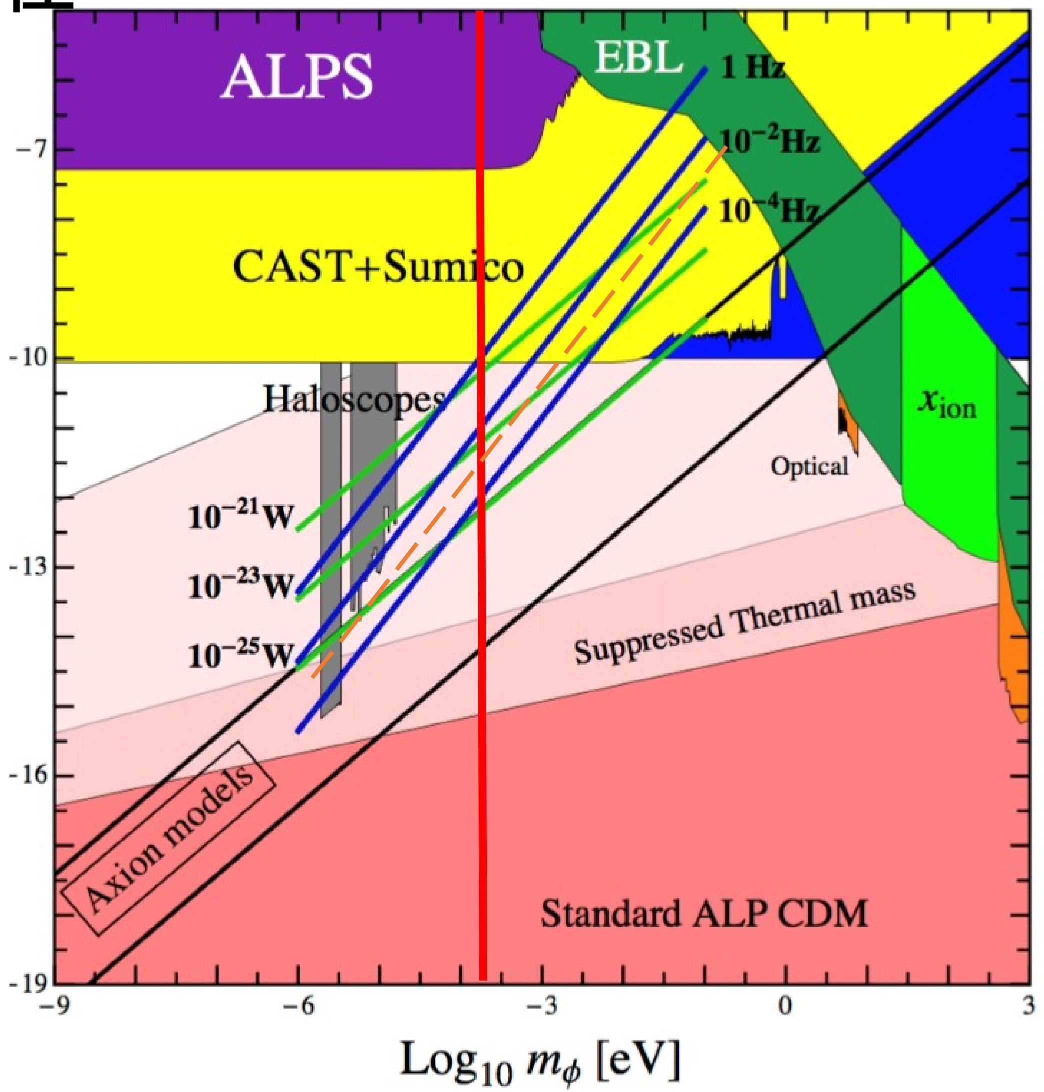
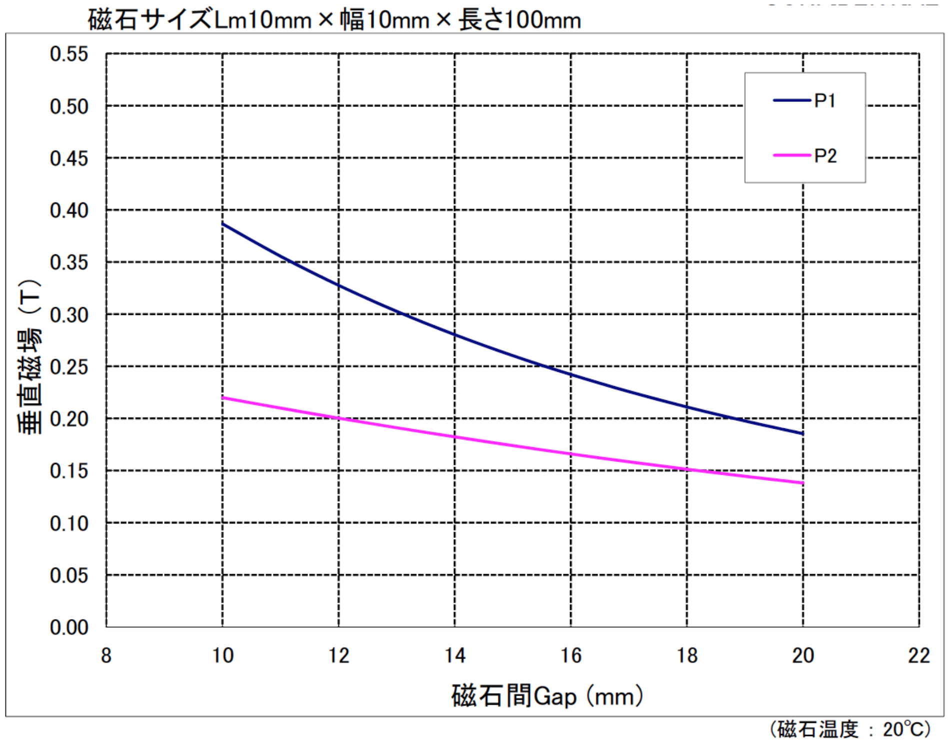


図２　ジョセフソン・パラメトリックアンプの増幅特性。 平均光子数１付近でのゲインは約 30 dB である。

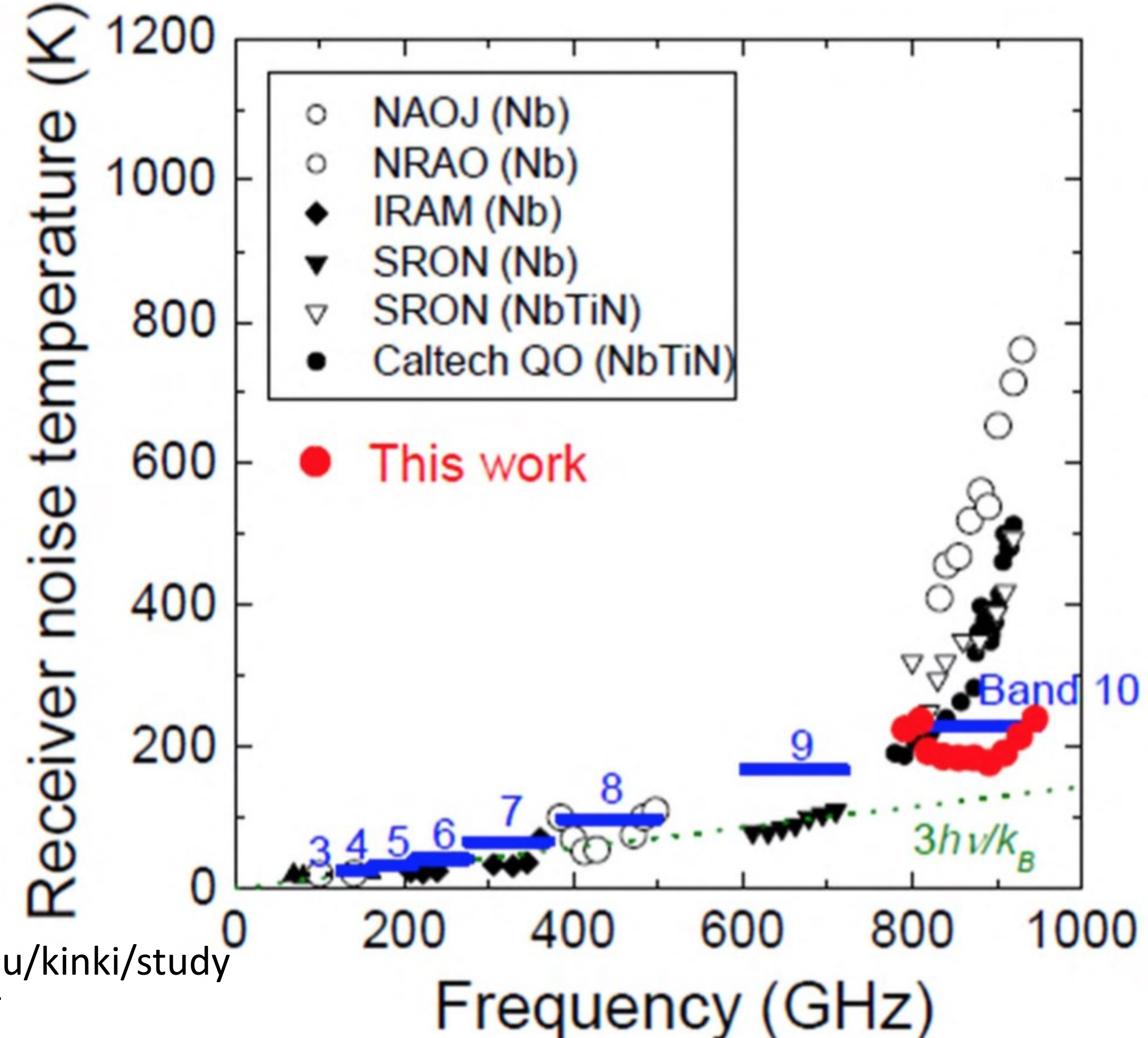


- 5T, 1㎡（R＝110cmディスク）はきつい
- 小さくて，強磁場は？
  - 例えば，15Tにしても9倍
    - ボア径
  - 難波さんのやってる超強磁場
    - 30T, 0.5cm×20cm ⇒ 6X6/200/5
- 大きくて，弱磁場は？
  - ネオジム磁石⇒1cmピッチで0.35T程度で，$5X10^{-3}$
  - 20m×20m＝400㎡ なら2倍稼げる…
  - 30m×30m＝900㎡なら4.5倍
  - SKの内壁半分に張り付ける
    - R=20m，L=40m＝2512㎡で12．5倍



垂直磁場計算結果

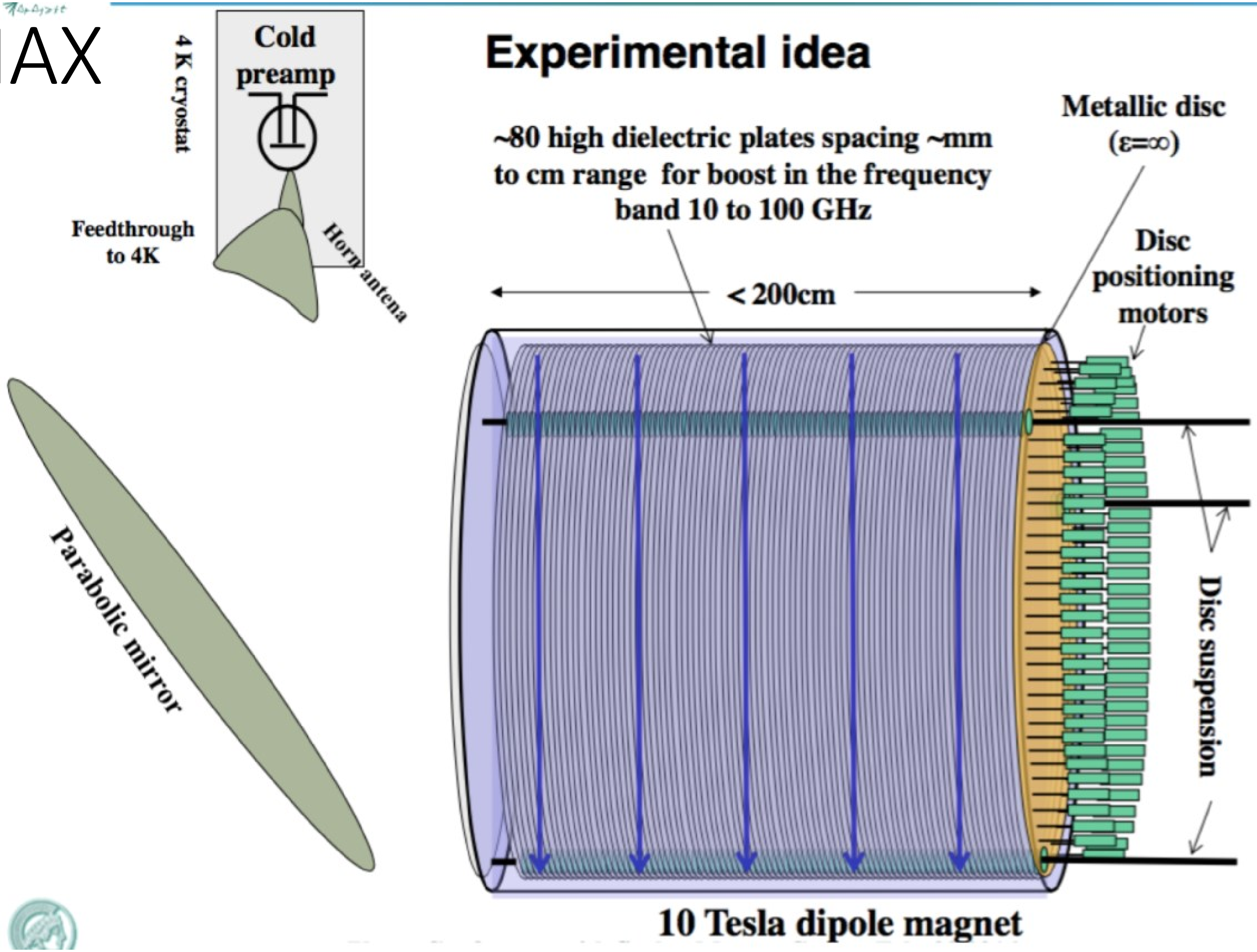
実はアンプの性能の向上も著しい



http://www.soumu.go.jp/soutsu/kinki/study group/2010/THz/2nd/2_04.pdf

MADMAX

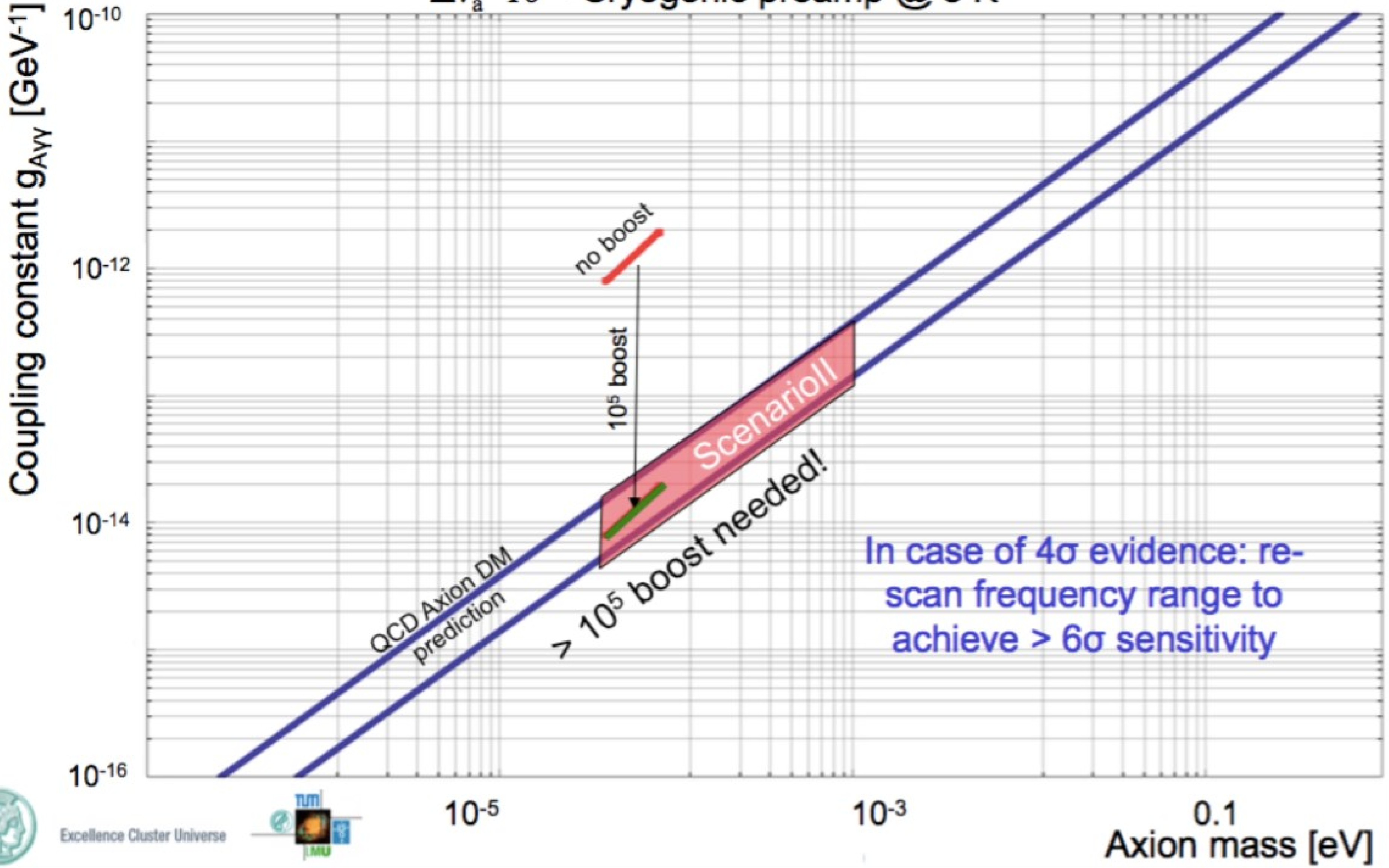
3 GHz⇔10 cm
10 GHz⇔ 3 cm
100 GHz⇔ 0.3 mm



First measurements: sensitivity

Expected 4σ detection sensitivity with and without boost

for 80 discs, 1m² surface, 10T B-field, τ=200h, 50MHz boost andwidth, $\Delta\nu_a=10^{-6}$; Cryogenic preamp @ 8 K



Excellence Cluster Universe

サマリを終えて

- ADMX
  - すごい勢い
- MADMAX
  - 雑音評価がなされていないのでは？

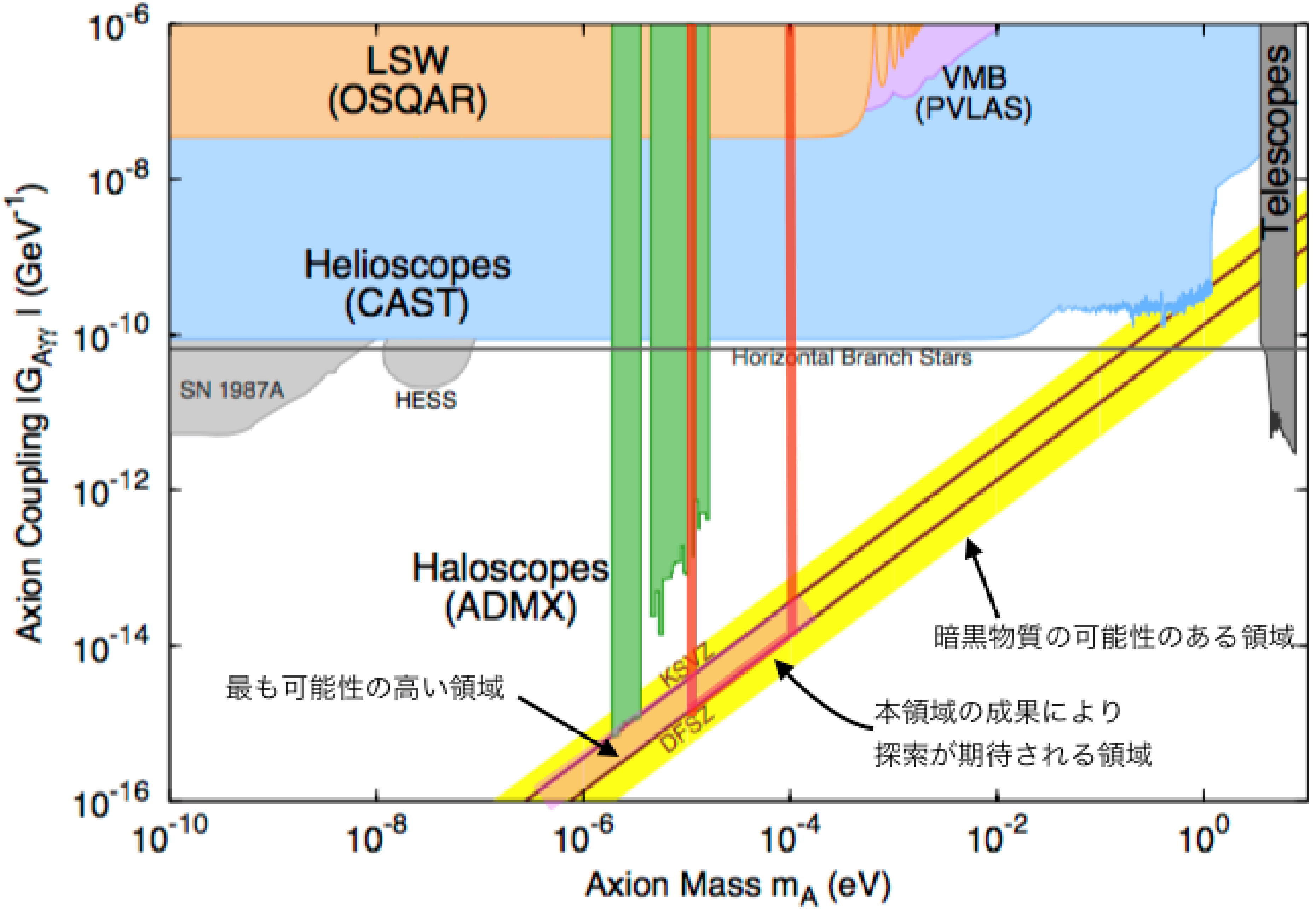
将来へのプラン

$$P_{\rm out} = \kappa g^2 V |\mathbf{B}_0|^2 \rho_0 \mathcal{G}_{\rm axion} \frac{1}{m_a} Q \,,$$

$$\mathcal{G}_{\rm axion} = \frac{\left(\int dV\, \mathbf{E}_{\rm cav} \cdot \mathbf{B}_0\right)^2}{|\mathbf{B}_0|^2 V \int dV\, |\mathbf{E}_{\rm cav}|^2} \,.$$

狙うものはアクシオン，そのついでにHP

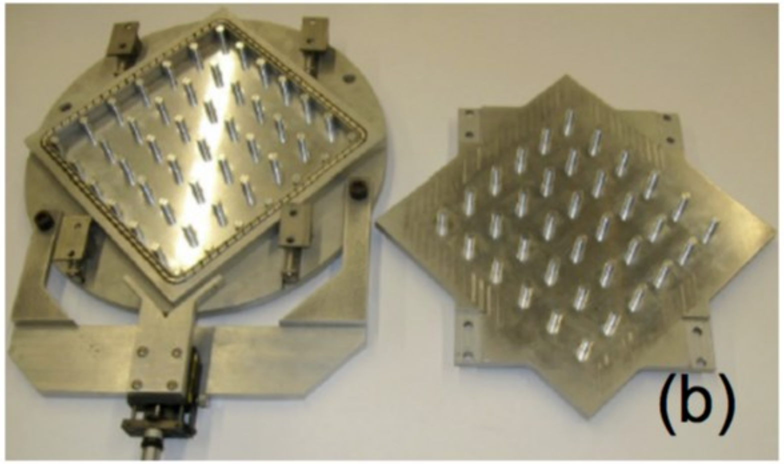
- 大型キャビティで2～25 GHz
  - 500L
  - Q値は控えめ
  - 手法としてはPhotonic band cavity
- 検出器は今あるもの（QLの4倍程度）
  - 積分時間で頑張る
    - 高精度のディッケスイッチが必須
- 磁場も今あるもの（8T）
  - 但し，Stored energy は巨大

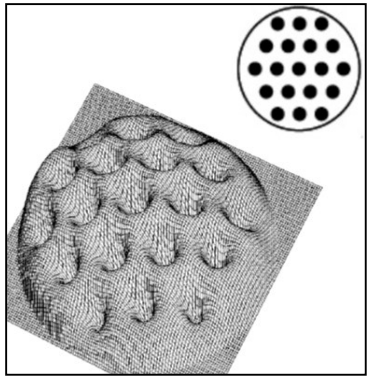


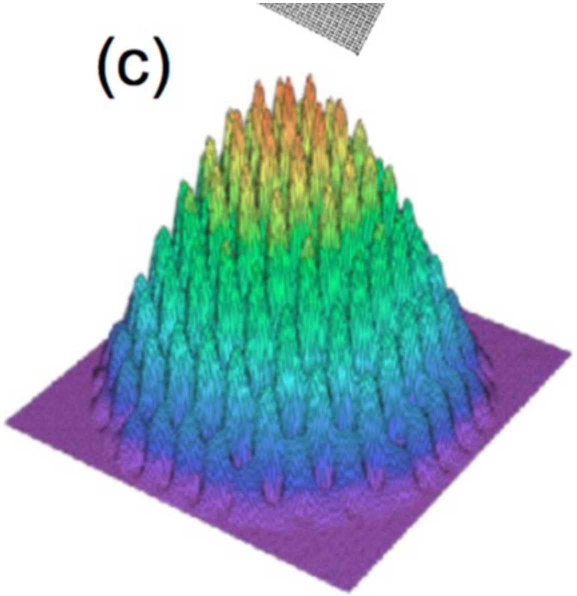
LSW
(OSQAR)
VMB
(PVLAS)
Telescopes
Helioscopes
(CAST)
Horizontal Branch Stars
SN 1987A
HESS
Haloscopes
(ADMX)
KSVZ
DFSZ
暗黒物質の可能性のある領域
最も可能性の高い領域
本領域の成果により
探索が期待される領域
Axion Coupling |G$_{A\gamma\gamma}$| (GeV^{-1})
Axion Mass m$_A$ (eV)
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
10^{0}

メタルポストアレイ

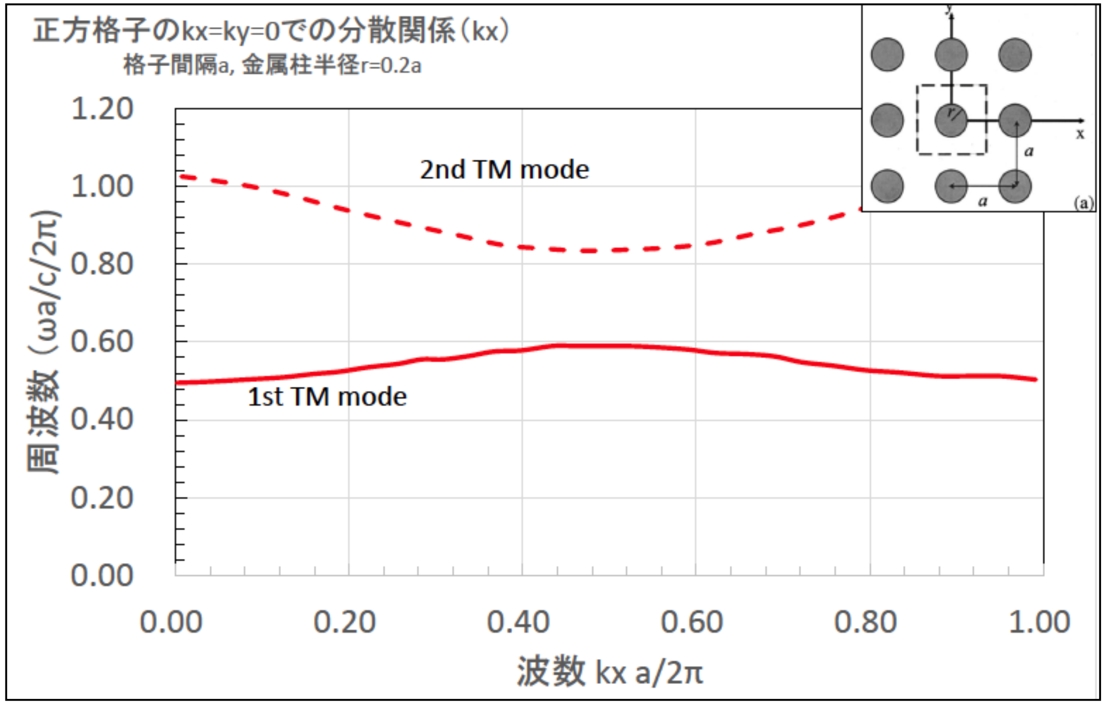
- TM$_{010}$モード様の大空洞がほしい（体積500ℓ）
- 世の中解析的な空洞ばかりではない
  - メタルポストアレイ
    - もともとADMXでも



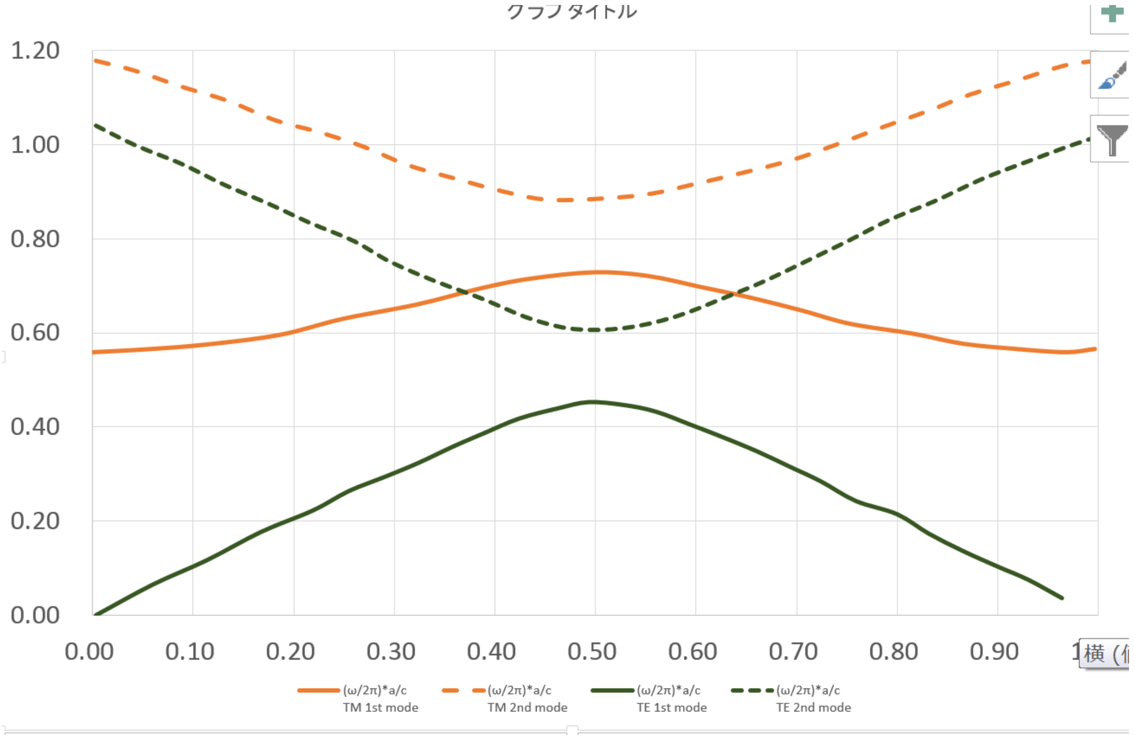




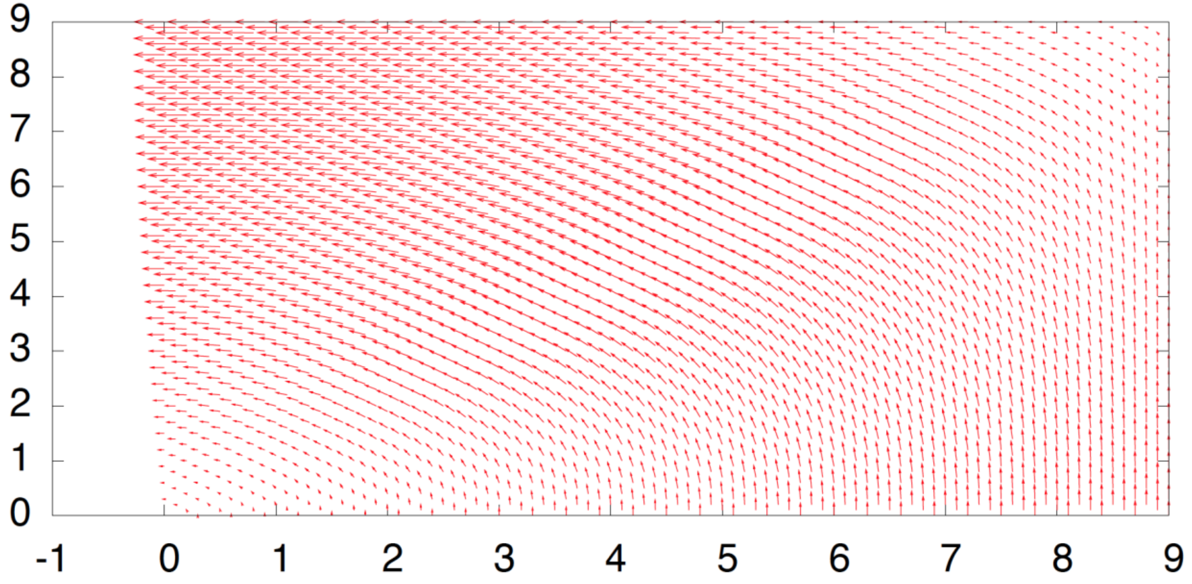
2次元無限の場合の計算



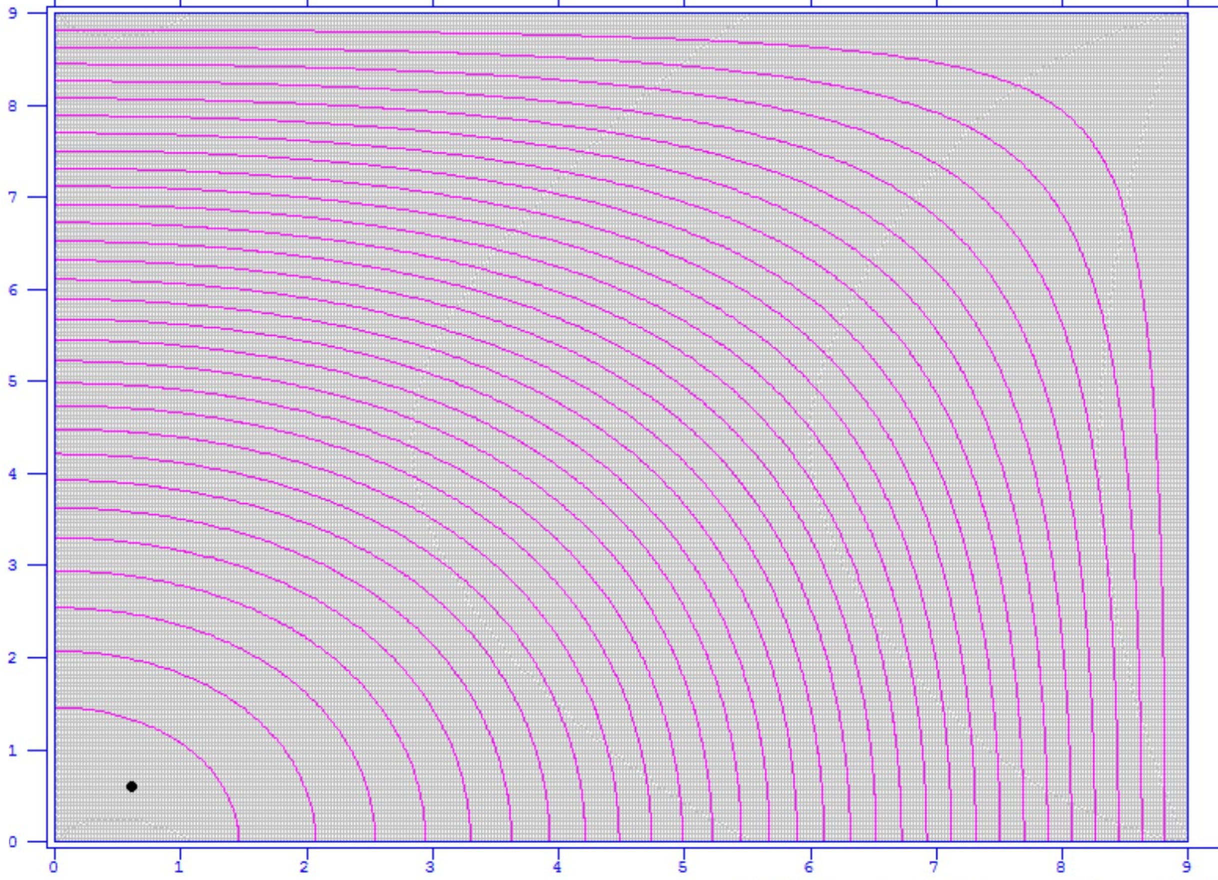
三角格子の場合のTE,TM モード

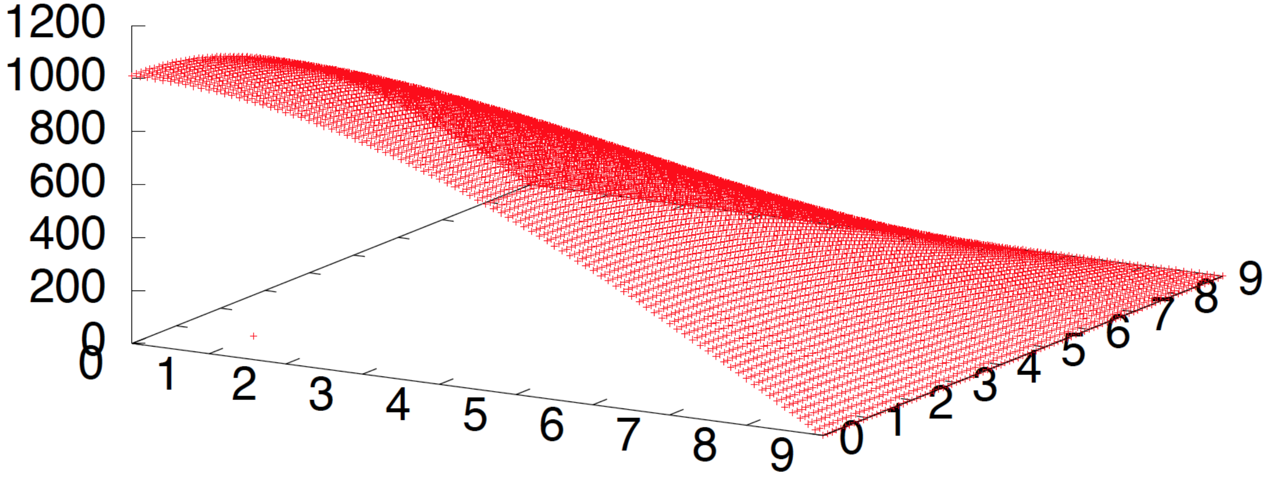


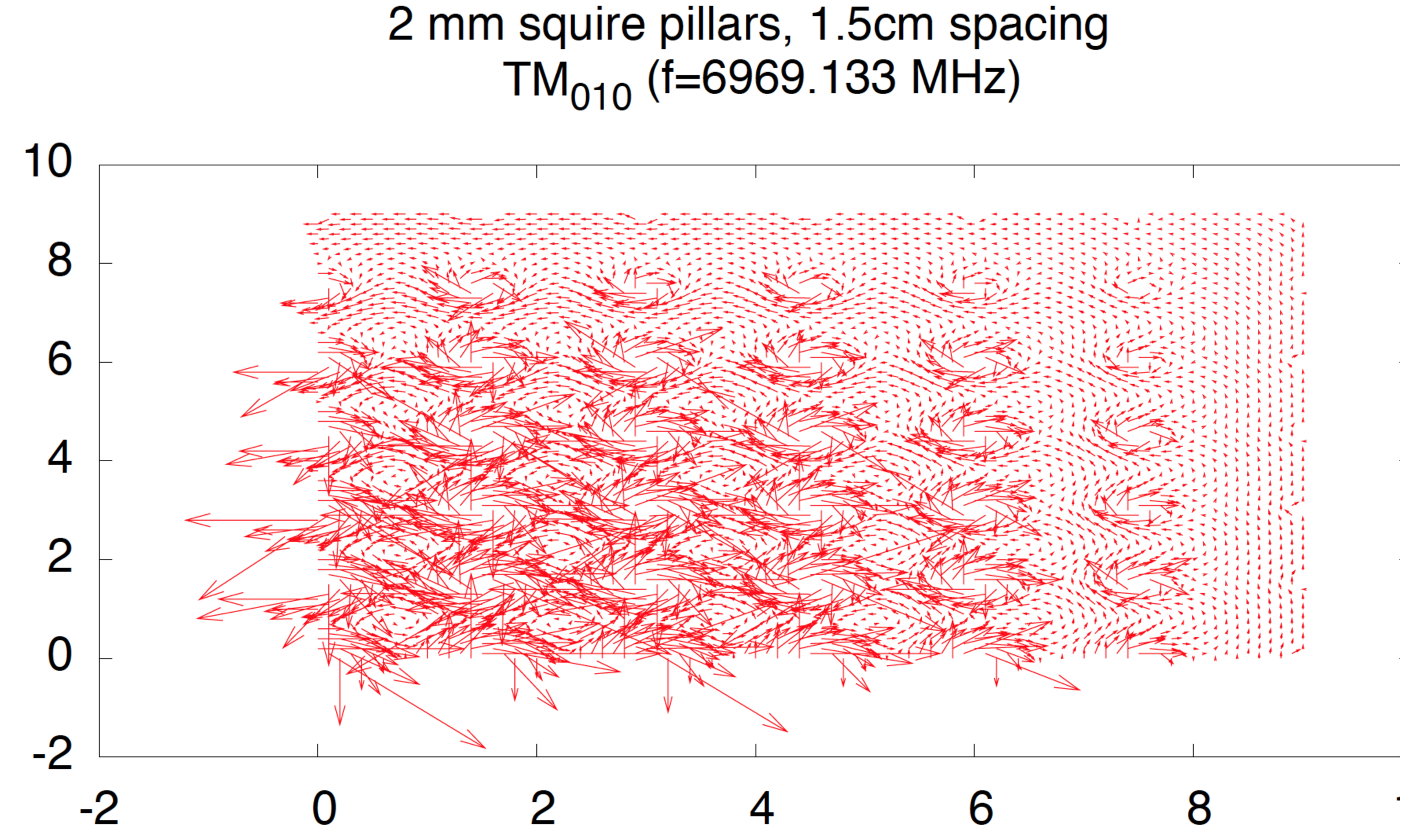
90 mm X 90mm Squire wave guide
TM_{010} mode (f=1177.6991 MHz)

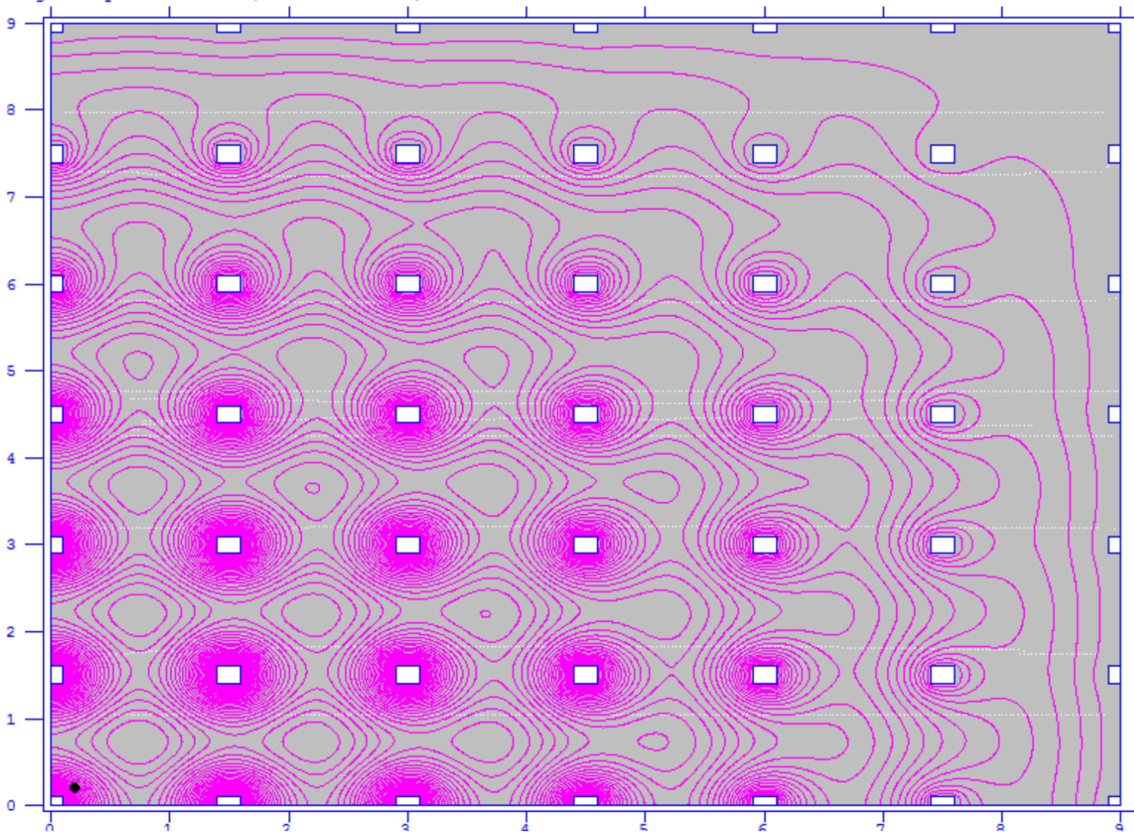


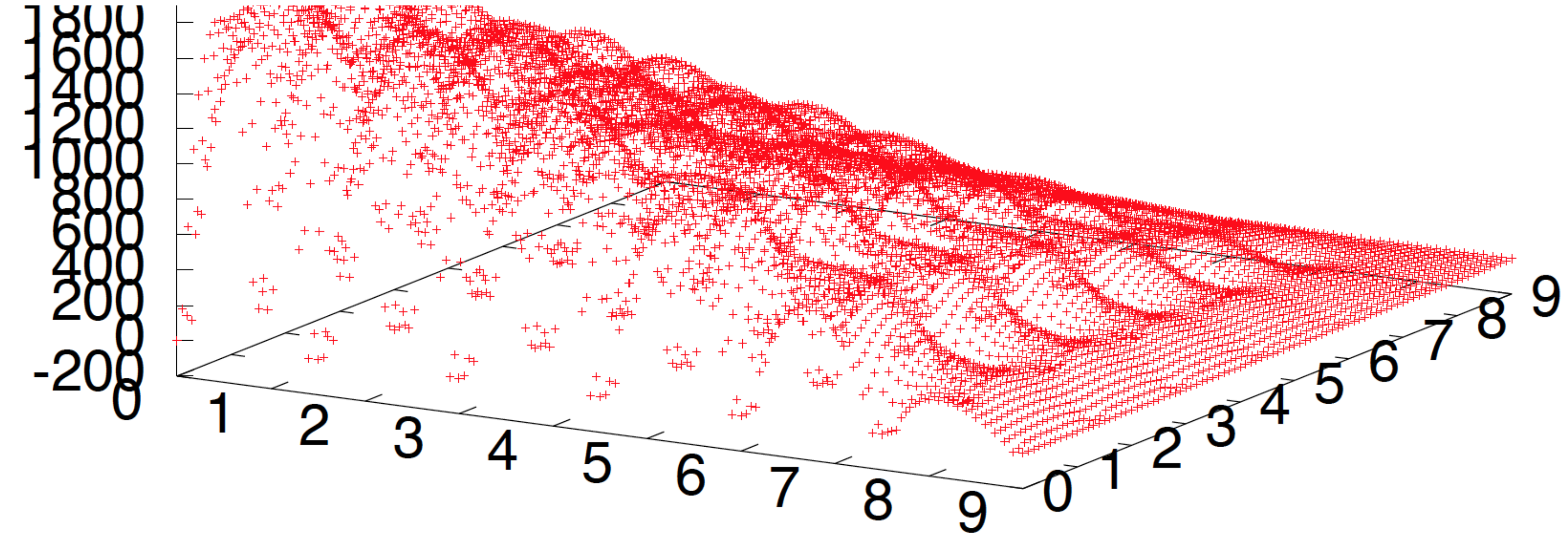
90 mm X 90mm Squire wave guide
TM_{010} mode (f=1177.6991 MHz)





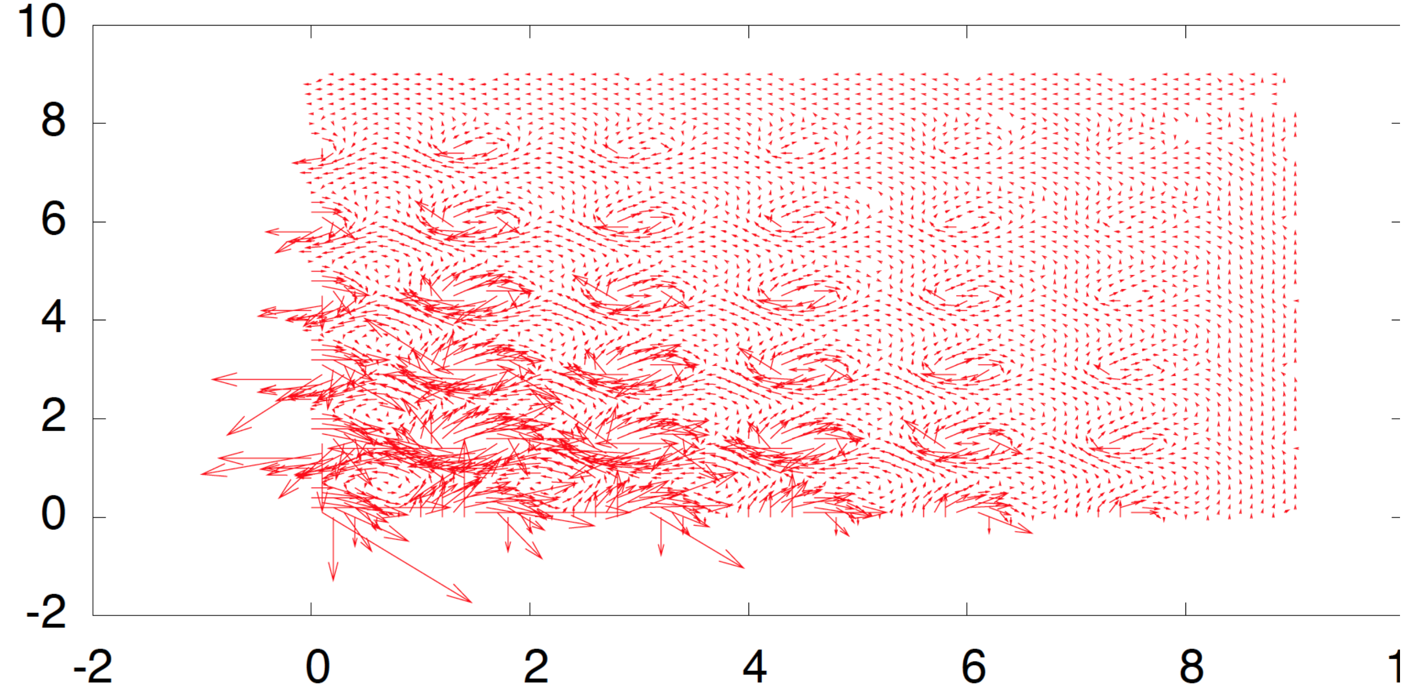

2 mm squire pillars, 1.5cm spacing
TM$_{010}$ (f=6969.133 MHz)
10
8
6
4
2
0
-2
-2
0
2
4
6
8

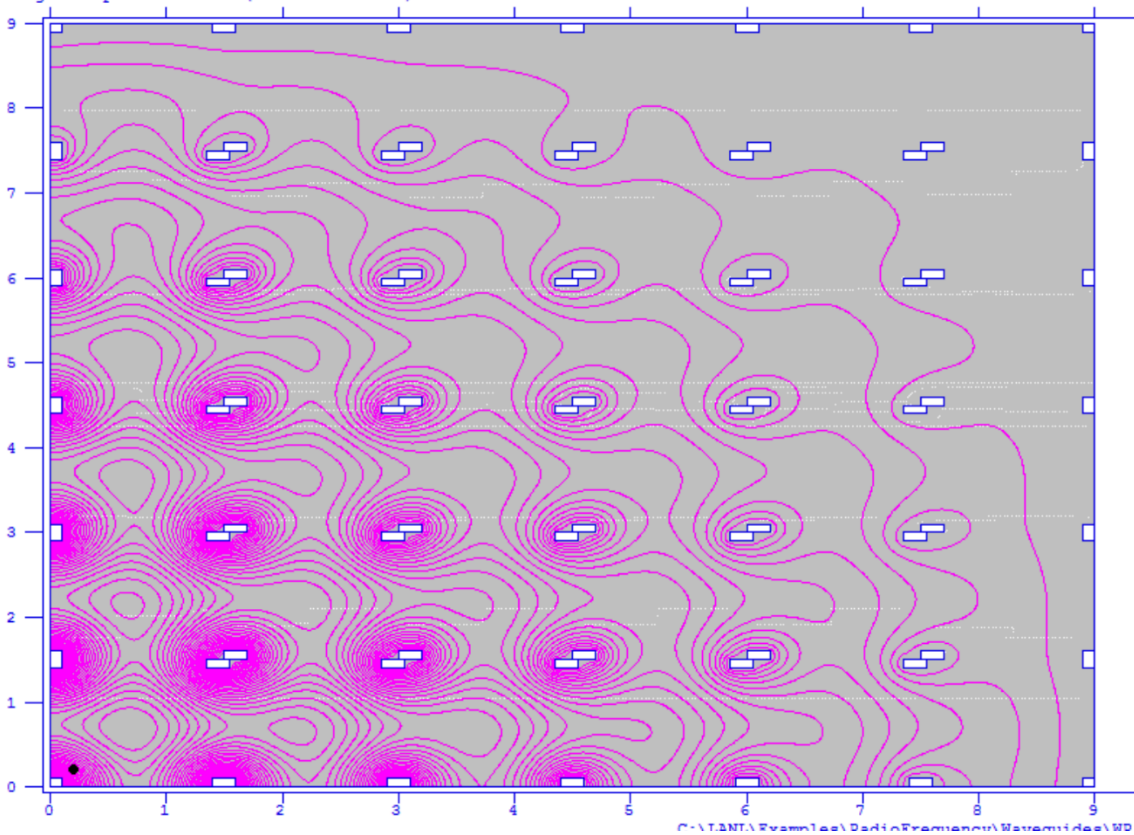


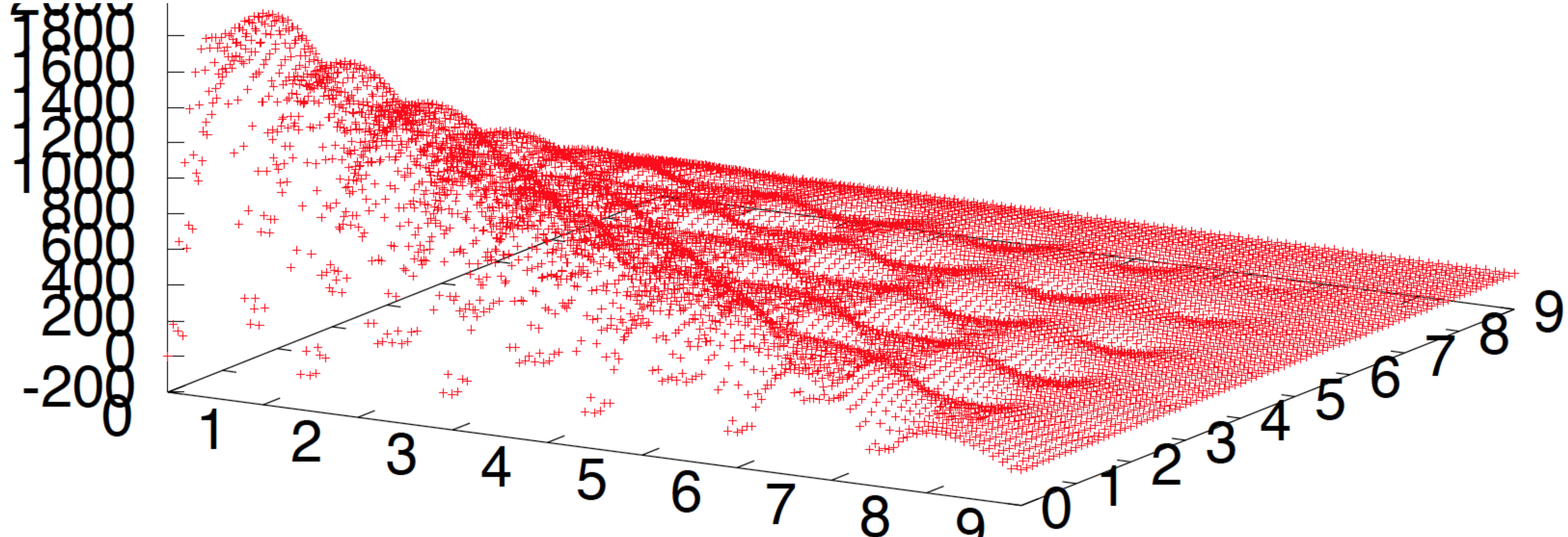

1800
1600
1400
1200
1000
800
600
400
200
0
-200
0 1 2 3 4 5 6 7 8 9
0 1 2 3 4 5 6 7 8 9

2 mm squire pillars, 1.5cm spacing -tune-

TM_{010} (f=7333.0851 MHz)







アクシオン質量 m(μeV)	周波数 f(GHz)	波長 λ(cm)	格子間隔 a(cm)	格子間隔aの均一さの目安a/Q(μm)		メタルポスト (r=0.2aの場合)	
				Q=2,000	Q=5,000	概数(本)	半径(mm)
10.5	2.5	12.0	6.0	30.0	12.0	13	12.0
21.0	5.0	6.0	3.0	15.0	6.0	559	6.0
42.0	10.0	3.0	1.5	7.5	3.0	2234	3.0
84.0	20.0	1.5	0.8	3.8	1.5	7854	1.6
105.0	25.0	1.2	0.6	3.0	1.2	13963	1.2

格子間隔aはTMの最低次モードを仮定し，a=0.5*c/f で計算

- 500L のメタルポストアレイを作成できた場合の探索時間

$$P_{\rm out} = \kappa g^2 V |\mathbf{B}_0|^2 \rho_0 \mathcal{G}_{\rm axion} \frac{1}{m_a} Q \,,$$

$$\mathcal{G}_{\rm axion} = \frac{\left(\int dV\, \mathbf{E}_{\rm cav} \cdot \mathbf{B}_0\right)^2}{|\mathbf{B}_0|^2 V \int dV\, |\mathbf{E}_{\rm cav}|^2} \,.$$

、	アクシオン質量 m(μeV)	周波数 f(GHz)	磁場 B(T)	空洞体積 V(L)	Q値	相互作用 g *1E15 (GeV^-1)	形状因子 C	信号強度 P(W)	雑音温度 Tn(K)	積分時間 t(時間)	10%のScan時間(day)
文献モデル(KSVZ)	21	5	5	5	1,000	7.80	0.66	6.69E-25	3.0	82,635.8	344316.0
文献モデル(DFSZ)	21	5	5	5	1,000	2.94	0.66	9.51E-26	3.0	4,090,790.4	17044959.8
本研究の成果を利用した場合(KSVZ)	21	5	8	500	2,000	7.80	0.50	2.59E-22	3.0	0.5	4.6
	42	10	8	500	2,000	15.60	0.50	5.19E-22	4.0	0.5	4.1
	84	20	8	500	2,000	31.19	0.50	1.04E-21	6.0	0.5	4.6
	105	25	8	500	2,000	38.99	0.50	1.30E-21	6.5	0.5	4.3
本研究の成果を利用した場合(DFSZ)	21	5	8	500	2,000	2.94	0.50	3.69E-23	3.0	27.2	226.6
	42	10	8	500	2,000	5.88	0.50	7.37E-23	4.0	24.2	201.4
	84	20	8	500	2,000	11.76	0.50	1.47E-22	6.0	27.2	226.6
	105	25	8	500	2,000	14.70	0.50	1.84E-22	6.5	25.5	212.7

※ 文献ではウィッグラー磁石 を用いているが，本研究ではソレノイド磁石を用いるため，磁場を大きく設定した．
形状因子は，理想的な場合で0.66であるので，本研究では0.5を仮定した．
また，アンプ雑音温度はカタログから読み取ったおおよその値

年	R&D		Physics	
2018	**Photonic Cavityの実証** (20cm×20cm程度) (f=2.8, 5.7 GHz) ・Mode profileの確認 ・TuningとQ値の両立		DAQ準備	
2019			Hidden Photon探索 (Test Cavityと小キャビティ) χ ～10^-10	ADMX Y2 (1～2GHz)
	高周波数化 f=20 GHzへジャンプ ⇒うまくいけば順次，常温でのHP探索へ	大型Cavityとクライオスタット作成		
2020		Engineering Run		ADMX Y3 (2～4GHz)
			Cryostat中でのHP探索 χ ～10^-12	
2021		Magnet作成		ADMX Y4 (4～6GHz)
		Engineering Run	Axion Run(中心付近10%)	
2022				ADMX Y5 (6～8GHz)
2023			Cavityをスイッチ	

広範囲探索では，Scan rateで劣る．
Q値か検出器感度の向上が必要