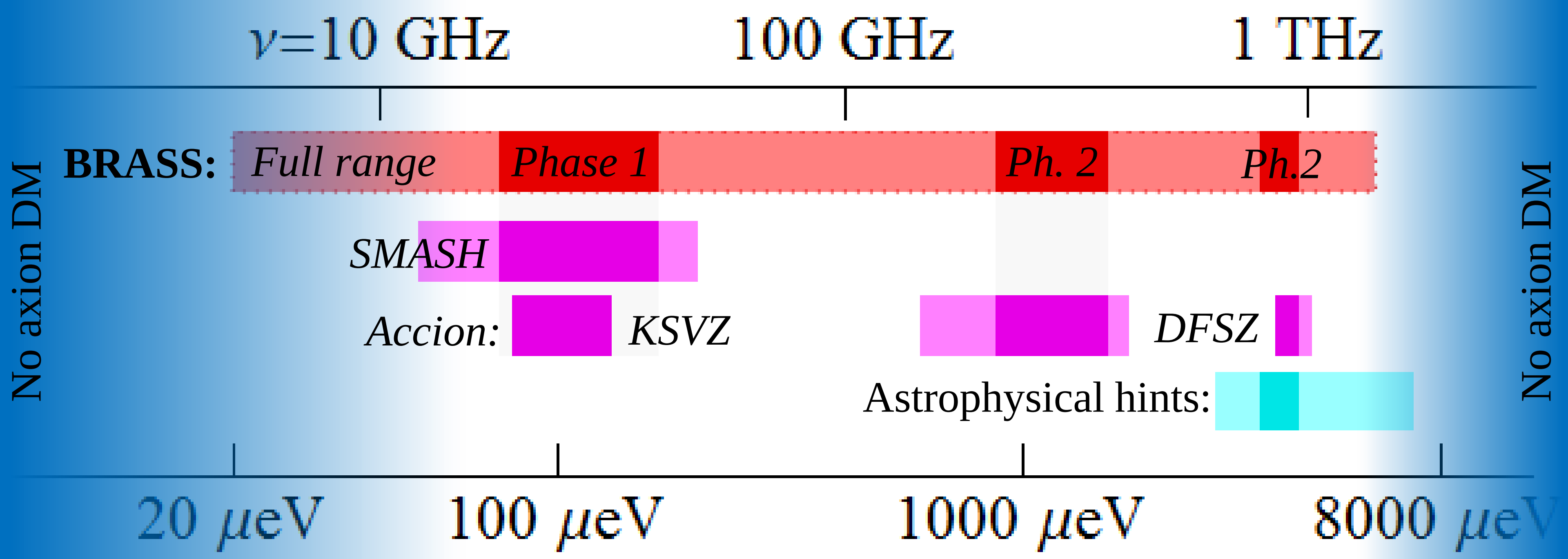
BRASS:
Broadband Radiometric Axion/ALP SearcheS



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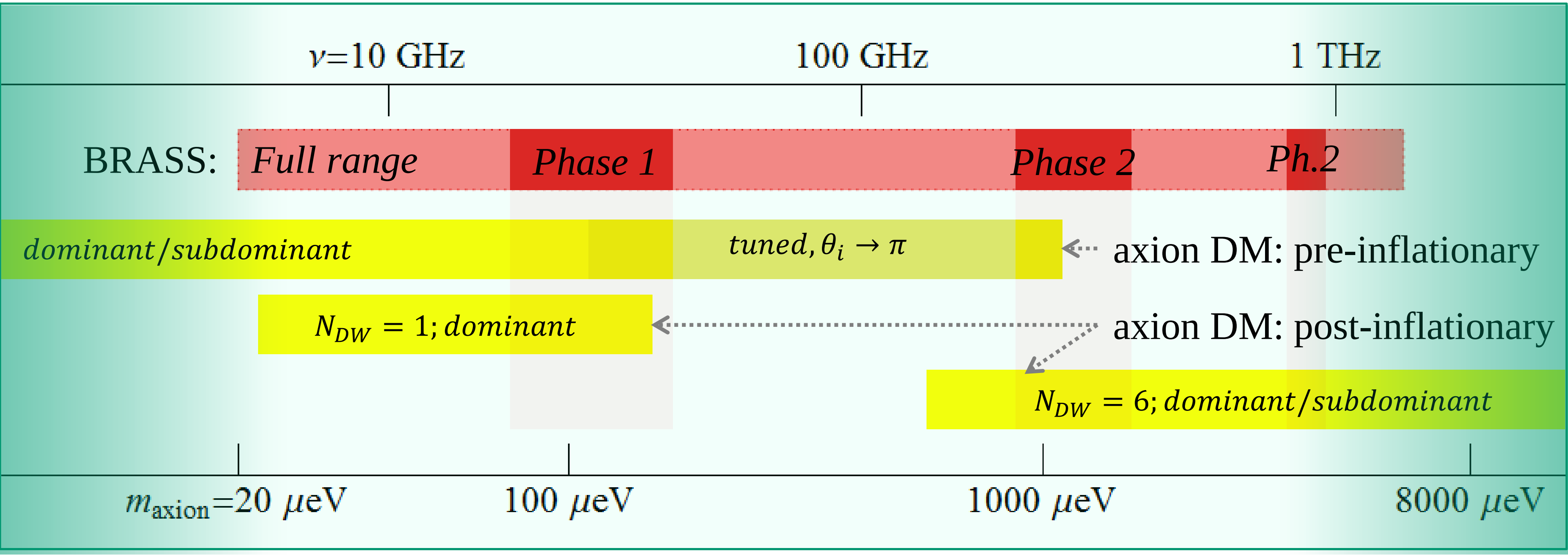
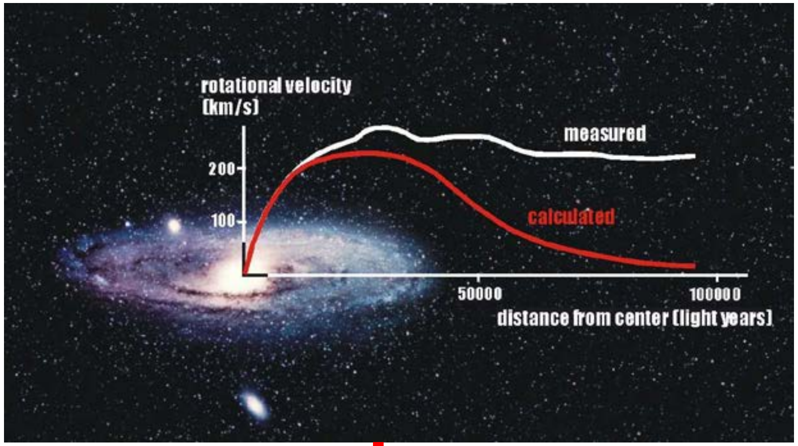
3 – Hamburg University of Technology. 4 – Deutsches Elektronen Synchrotron (DESY).

Main Goal of BRASS

Establishing a versatile instrumental framework for axion, ALP and hidden photon dark matter searches in the 10 GHz – 1 THz range of frequencies.

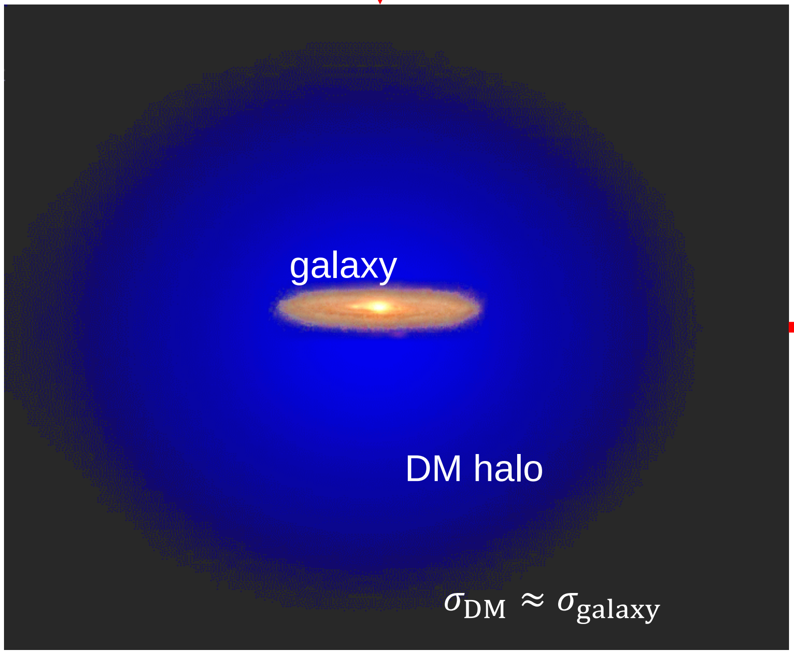


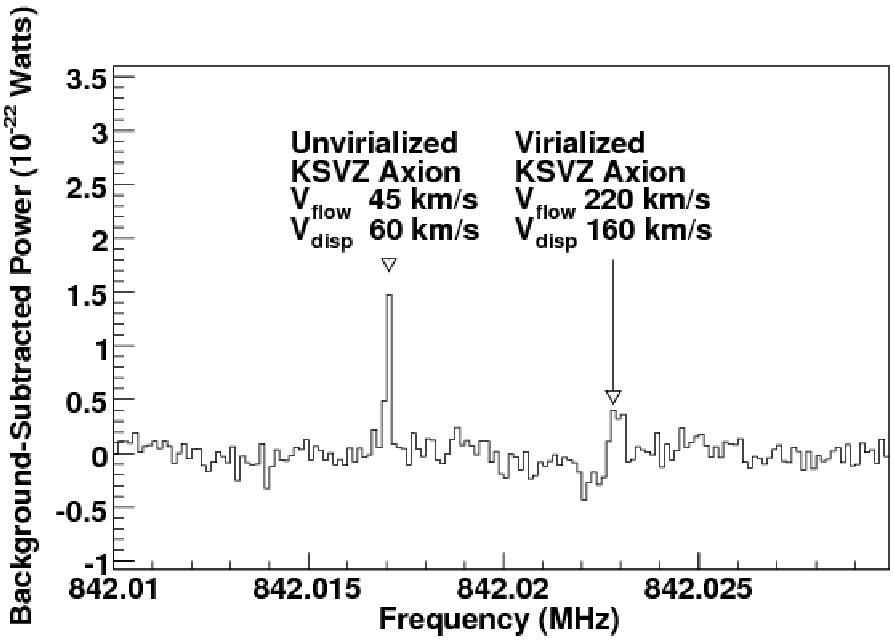
Direct WISP DM Searches



- Dark Matter: sits in a halo, can be virialized with a velocity dispersion similar to the galactic velocity dispersion (σ_g ~ 300 km/s).
- WISP DM: WISP-photon conversion: expect a line with width of

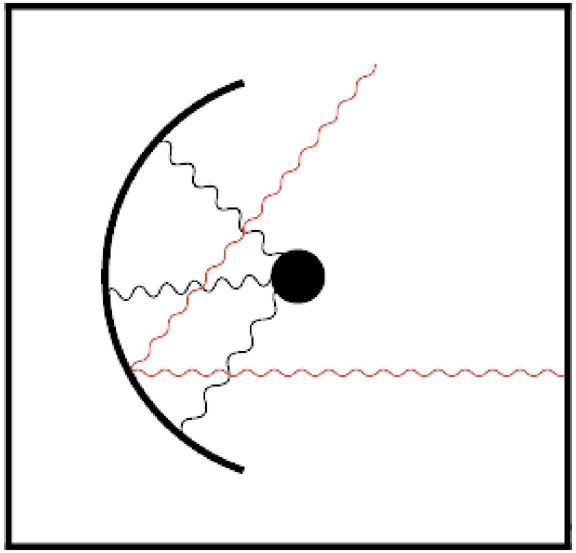
$$\Delta\nu/\nu \sim (\sigma_g/c)^2 \sim 10^{-6}$$





"Dish Antenna" for WISP DM Searches

- WISP DM conversion to photons at conducting surface. Signal focusing via a parabolic/spherical mirror (Horns+ 2013)



- Expected sensitivity:

Axion/ALP:

$$g_{\phi\gamma\gamma,\,\mathrm{sens}} = \frac{3.6\times10^{-8}}{\mathrm{GeV}}\left(\frac{5\,\mathrm{T}}{\sqrt{\langle|\mathbf{B}_{||}|^2\rangle}}\right)\left(\frac{P_{\mathrm{det}}}{10^{-23}\,\mathrm{W}}\right)^{\frac{1}{2}}\left(\frac{m_\phi}{\mathrm{eV}}\right)\left(\frac{0.3\,\mathrm{GeV/cm^3}}{\rho_{\mathrm{DM,halo}}}\right)^{\frac{1}{2}}\left(\frac{1\,\mathrm{m^2}}{A_{\mathrm{dish}}}\right)^{\frac{1}{2}}$$

Hidden photons:

$$\chi_{\mathrm{sens}} = 4.5\times10^{-14}\left(\frac{P_{\mathrm{det}}}{10^{-23}\,\mathrm{W}}\right)^{\frac{1}{2}}\left(\frac{0.3\,\mathrm{GeV/cm^3}}{\rho_{\mathrm{CDM,halo}}}\right)^{\frac{1}{2}}\left(\frac{1\,\mathrm{m^2}}{A_{\mathrm{dish}}}\right)^{\frac{1}{2}}\left(\frac{\sqrt{2/3}}{\alpha}\right)$$

DM Searches: Broadband vs. Resonant

- Scanning a mass range (m_1,m_2=αm_1).
- A broad band measurement is more efficient than a narrow band one if

$$t_{broad} < t_{narrow} N_{mes}$$

- If a narrow band measurement has "boost" factor Q, this implies

$$1 + Q \log \alpha > \left(\frac{T_b}{T_n}\right)^2 \left(\frac{B_b}{B_n}\right)^{-4} \left(\frac{V_b}{V_n}\right)^{-2} \left(\frac{G_b}{G_n}\right)^{-2}$$

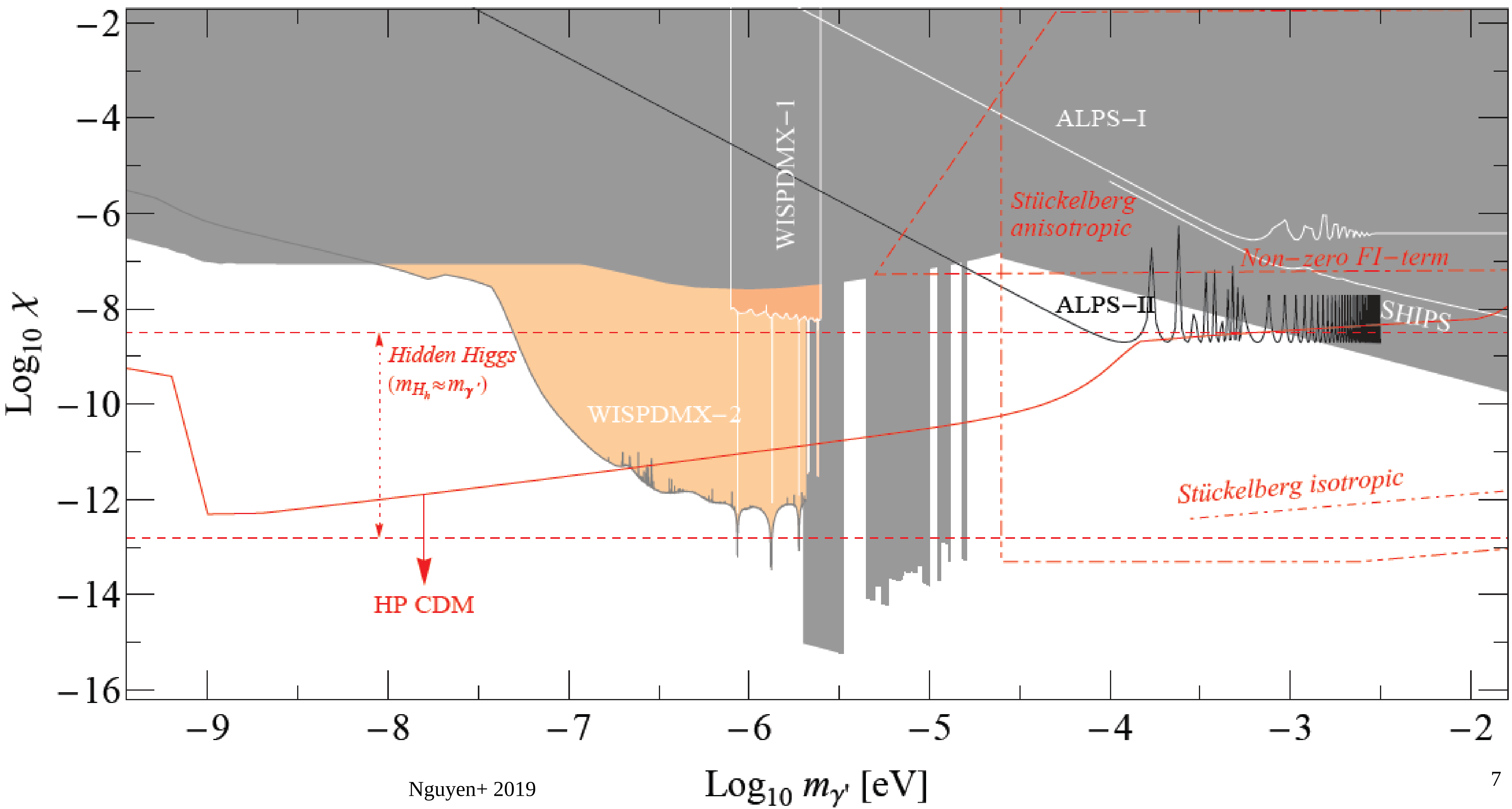
- For typical $T_b = 100T_n$, $B_b = 1.0\,B_n$, $V_b = 100V_n$, and $G_b = 0.01G_n$, to scan as efficiently over a decade in mass, a narrow band experiment must have Q<10000.
- Hence, boosting is very good to have when you know where to search.
- "Boosted" searches: ADMX, CULTASK, MADMAX: 1 – 100 GHz.
- Broadband searches: BRASS: 20 – 1000 GHz.
- Broadband searches: sensitivity is an issue.

WISPDMX: HP DM Search at 10-500 MHz

Nguyen+ 2019

WISPDMX: HP DM in neV to μeV range

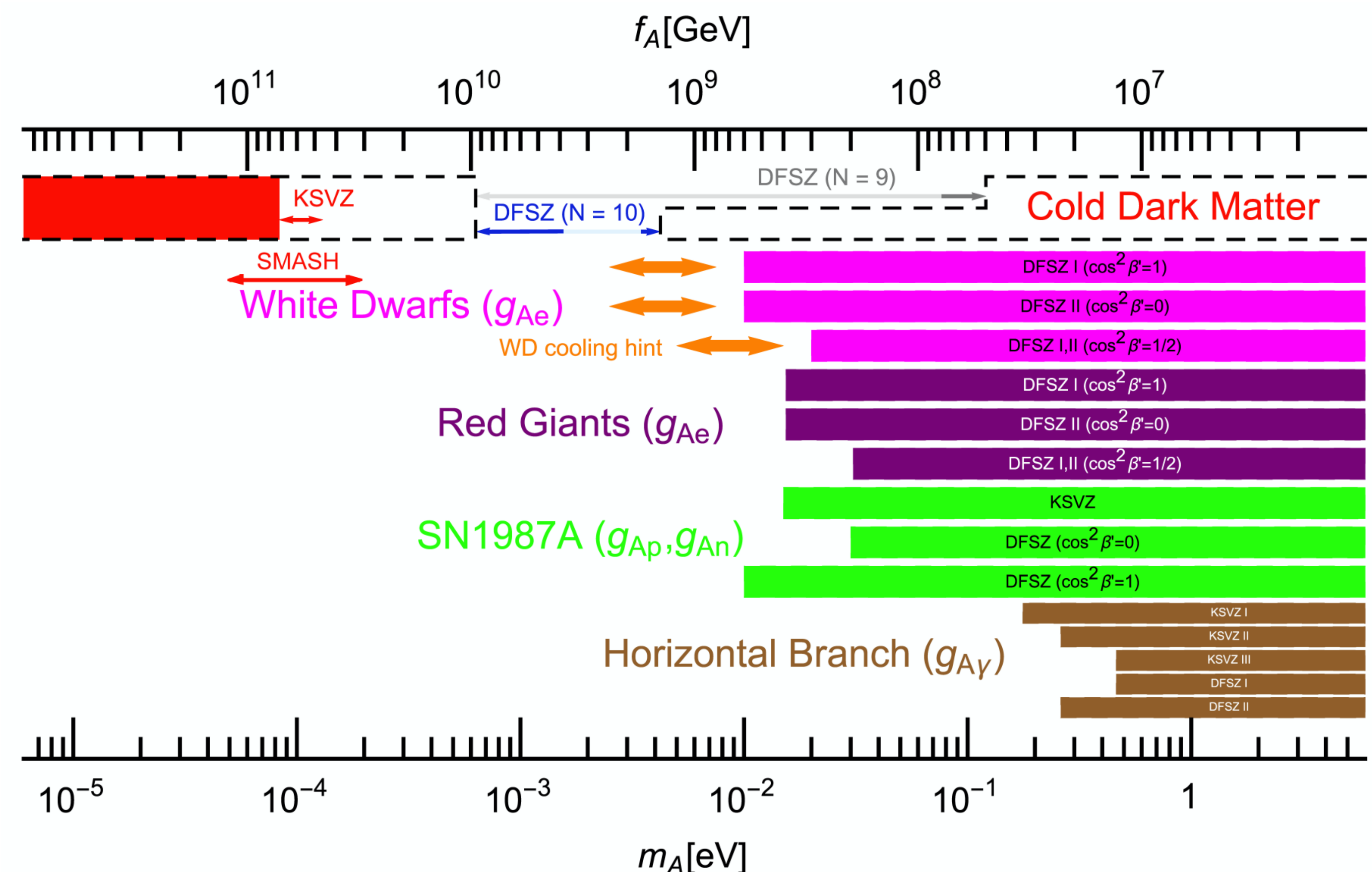
- WISPDMX: resonant and broadband search in the 0.01-500 MHz range.
- Combining a tunable resonant cavity with broadband recording.



Nguyen+ 2019

Axion DM Searches: Motivation

- Axion DM: the 10^{-5}–10^{-1} eV (2.4 GHz – 24 THz) range is best motivated.
- Effective approaches needed to cover this range. BRASS could be one.



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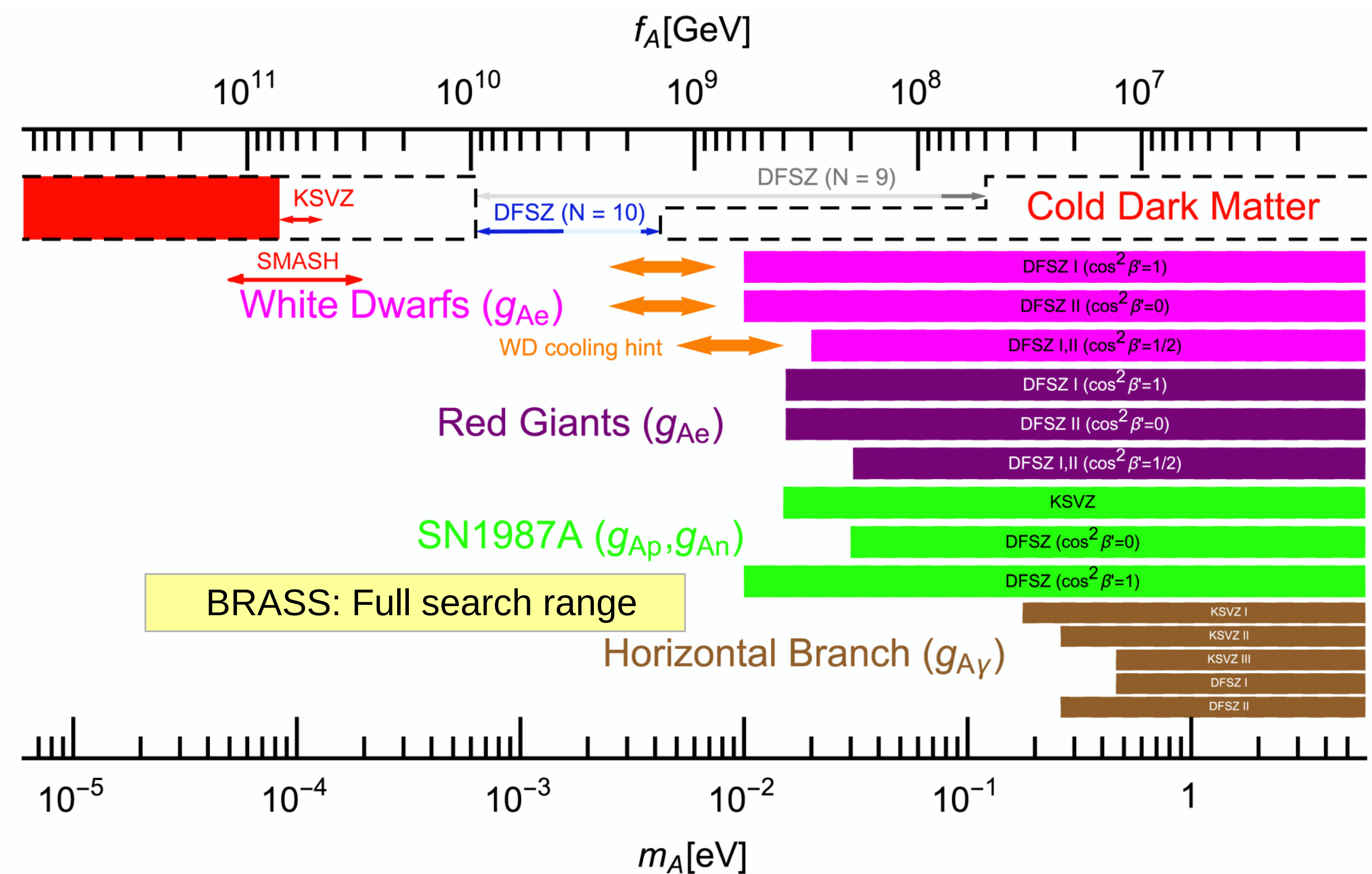
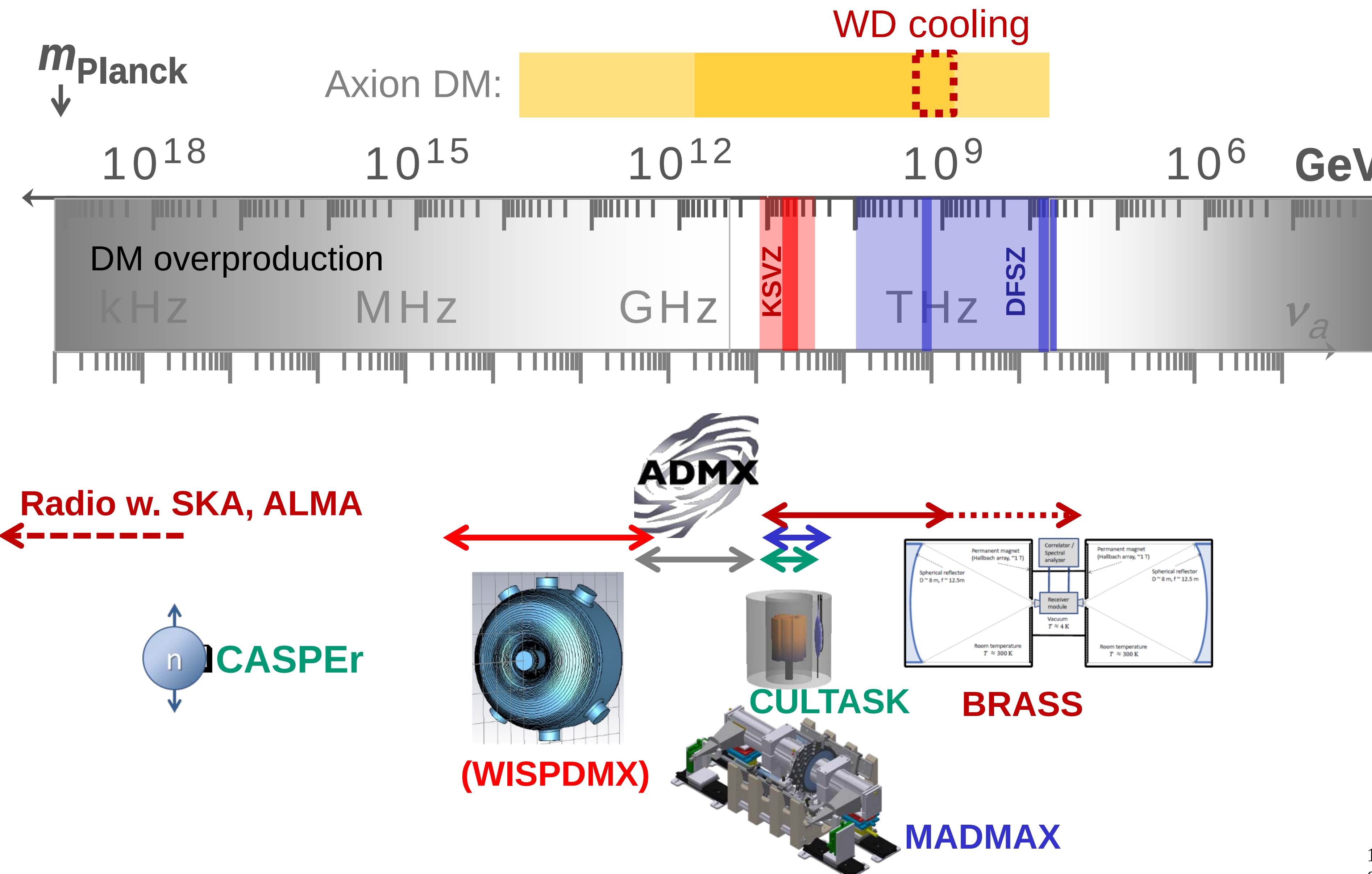


Axion/ALP DM Searches: Experiments



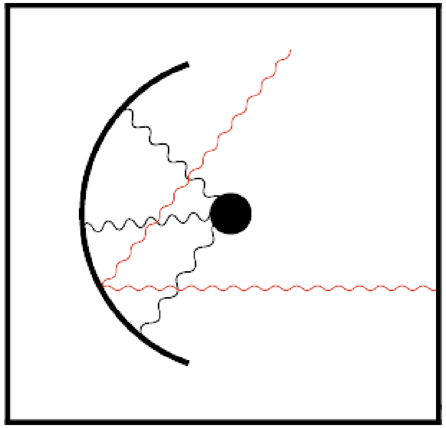
Broadband Conversion Methods

- Employing spherical reflectors enhance (focus) the near field EM signal from the reflector surface which arises due to its interaction with WISP dark matter (Horns et al. 2013). Promising for masses above 10 μeV.
- Modifications of the original concept:
  -- MADMAX: boost by multiple conversion surfaces (Caldwell+ 2016) for ~10-80 GHz range
  -- BRASS: magnetized conversion surface for 20 – 1000 GHz range.

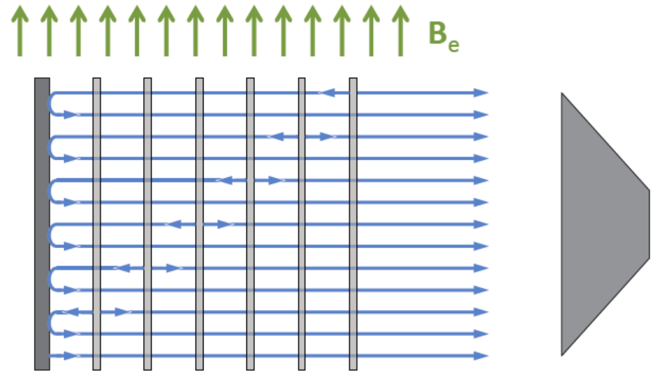
Great potentials for synergies with mm, sub-mm detection technology

Sensitivity $\propto B^2 A \; T_n^{1/2}$

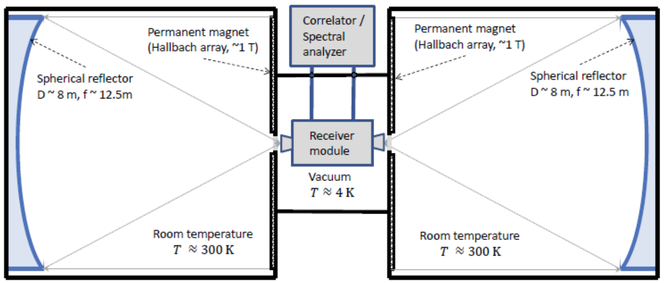
DISH: Original



MADMAX



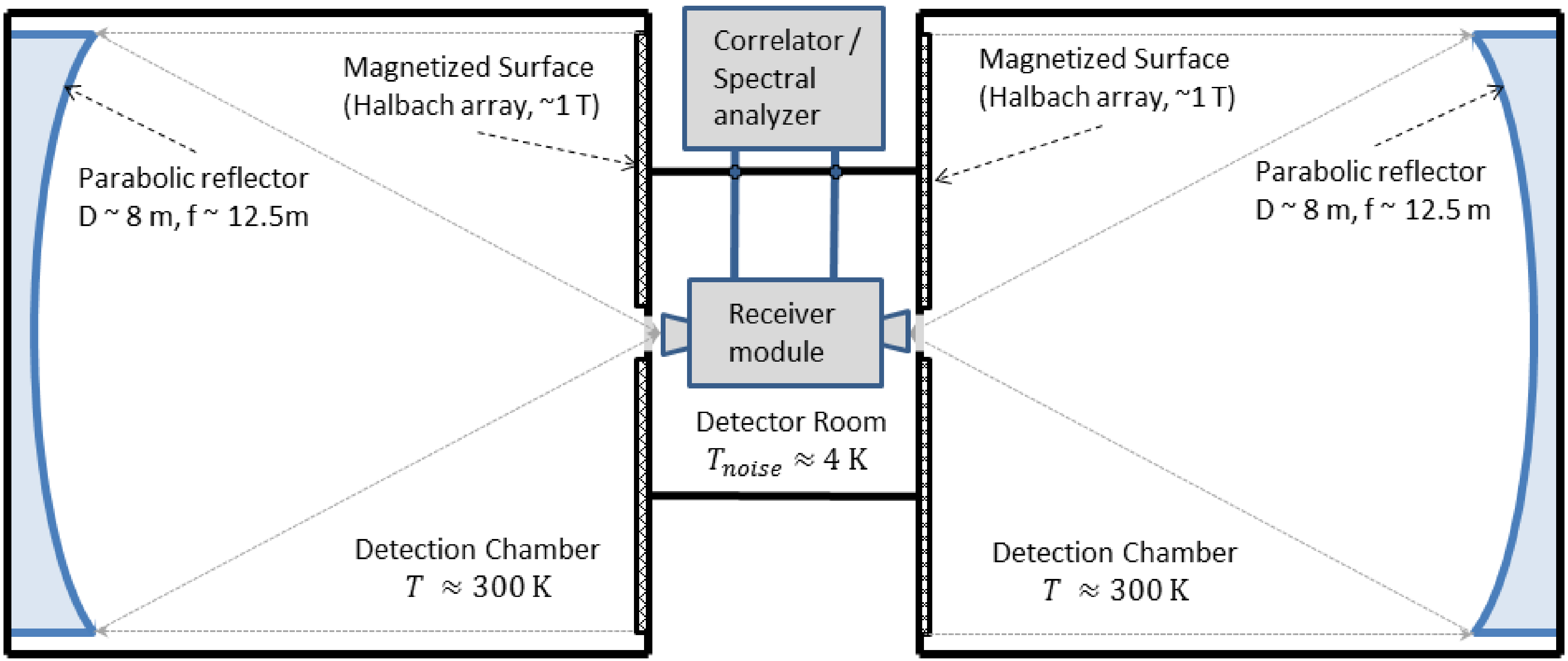
BRASS



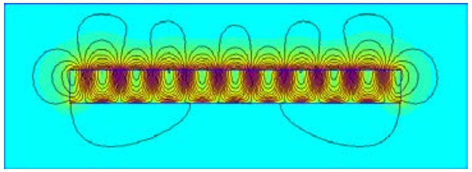
Conceptual Design for BRASS

$B^2\,A = 100\ T^2\ m^2$

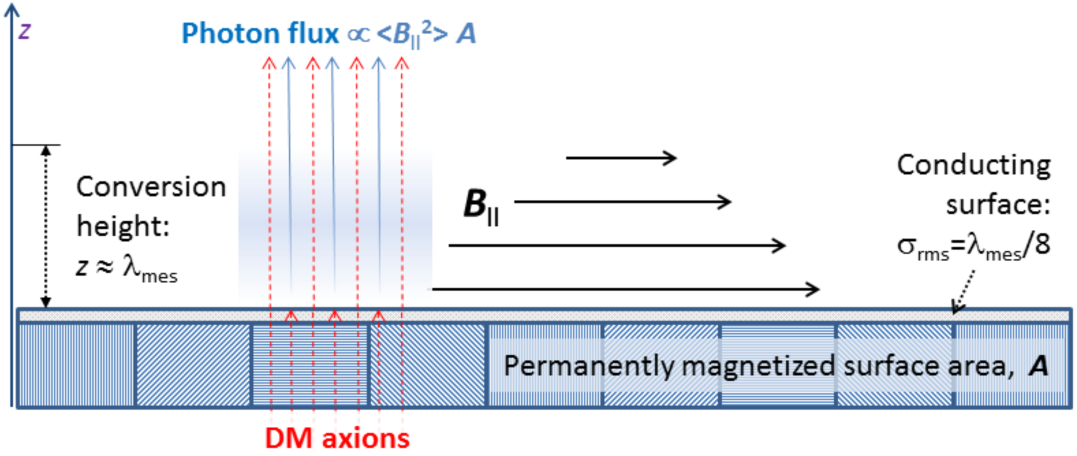
- Broadband Radiometric Axion/ALP SearcheS:
  - -- Flat, permanently magnetized surface (Halbach array; 100 m^2, B~1T).
  - -- Focusing the signal with a parabolic reflector.
  - -- Broadband recording (16+ GHz bandwidth, spectral resolution of 10^{-7}).
  - -- Correlating signals from multiple modules.
  - -- Natural synergy with ALMA/APEX and EHT VLBI developments.



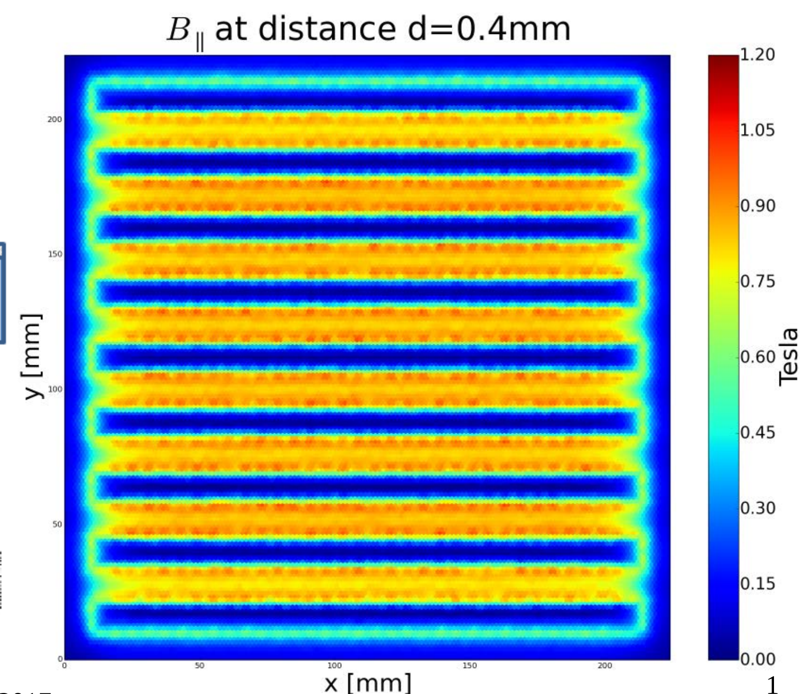
Magnetized Conversion Surface



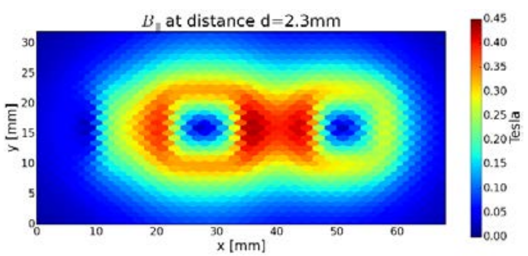
- ❑ Halbach array configuration to optimize the parallel B-field component.
- ❑ $Nd_2Fe_{14}B$ magnets: B_{max} ~ 1.4T, for room temperature operation.
- ❑ RE-Ba-Cu-O magnets: B_{max} ~ 10T at T~30K (Tomita &Murakami 2003)
- ❑ Potential use of thin dielectric layers to boost a specific band.

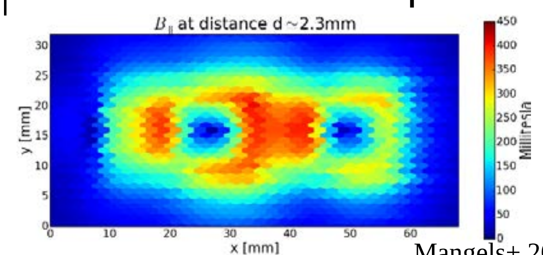


Simulated17x17 Halbach array:



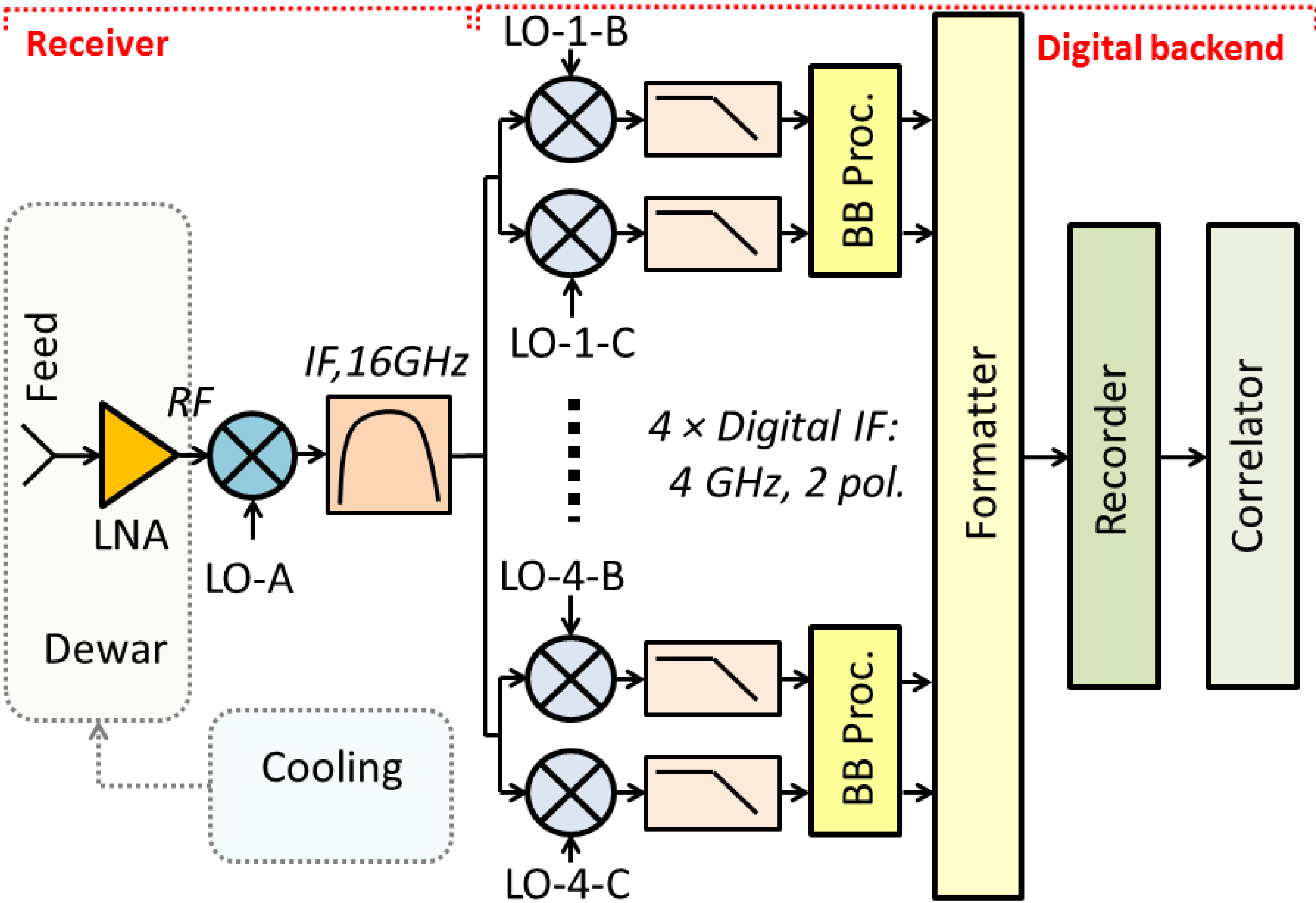
Simulated and measured $B_{||}$ in a 4x1 Halbach stripe



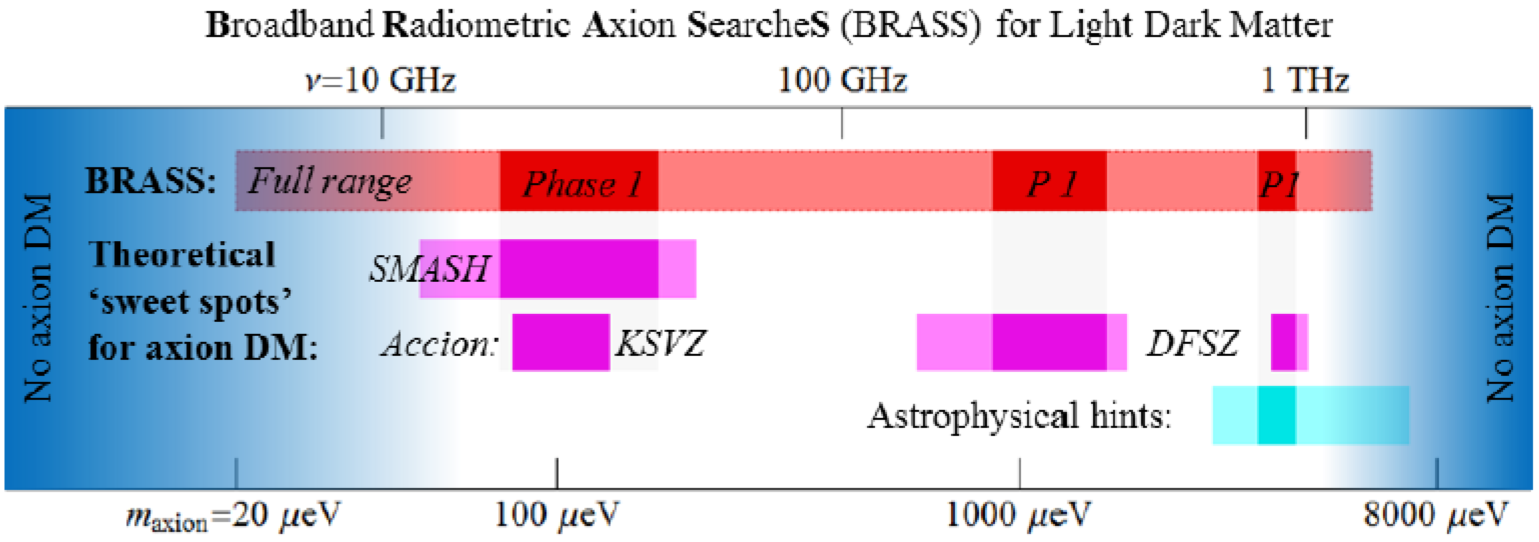


Mangels+ 2017

Detector Frontend & Backend



Prioritized Search Bands

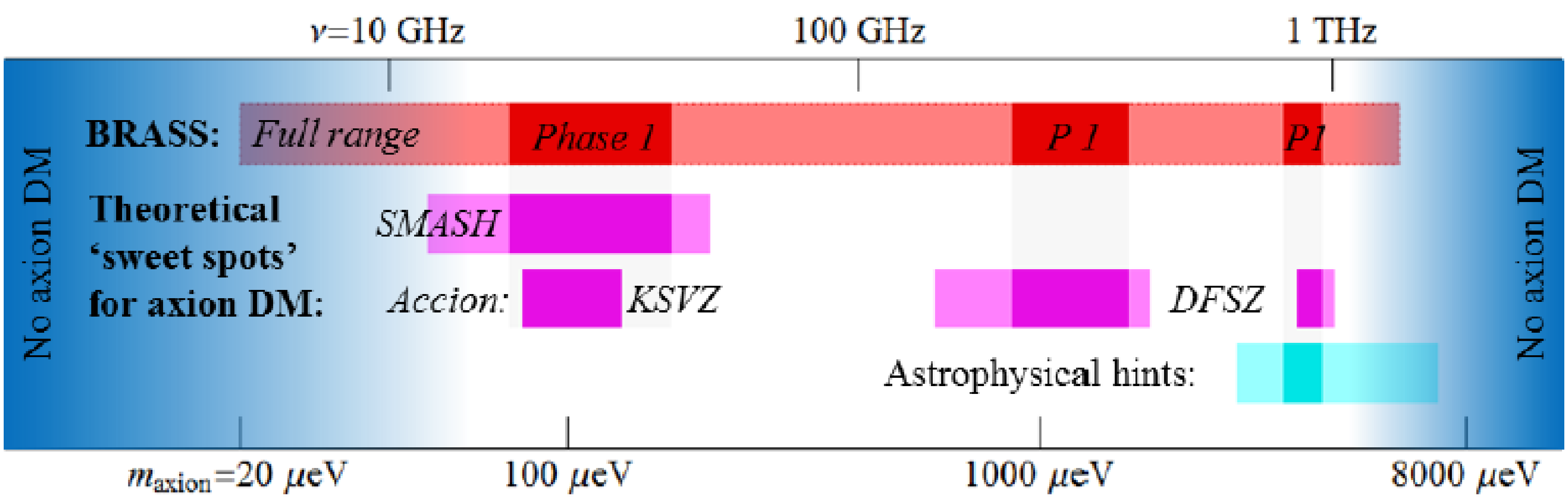


Axion Model		m_{axion} [meV]	ν [GHz]	P_{DM} [10^{-26} W]	W_{DM} [kHz]	Bands
SMASH		0.05–0.20	12.0–48.1	7.1	0.6–2.6	U,K,Q
Accion:	KSVZ	0.08–0.13	19.2–31.3	7.1	1.0–1.7	K
	DFSZ I	0.60–1.70	144–409	2.6	7.7–21.9	APEX 1-3
	DFSZ II	3.50–4.20	842–1010	4.6	45.0–54.0	ALMA 9,10

BRASS 1. *SMASH/KSVZ:* 0.07–0.14 meV: 18–32 GHz – K/Ka band
BRASS 2. *DFSZ I a:* 0.88–1.14 meV: 213–275 GHz – APEX 1 band
BRASS 3. *DFSZ I b:* 1.14–1.54 meV: 267–370 GHz – APEX 2 band
BRASS 4. *DFSZ II:* 3.27–3.95 meV: 787–950 GHz – ALMA 10 band

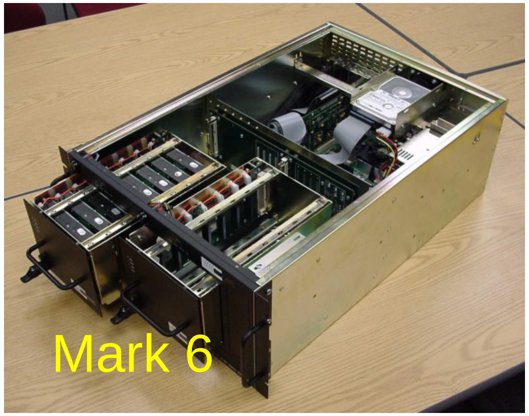
BRASS Status and Plans

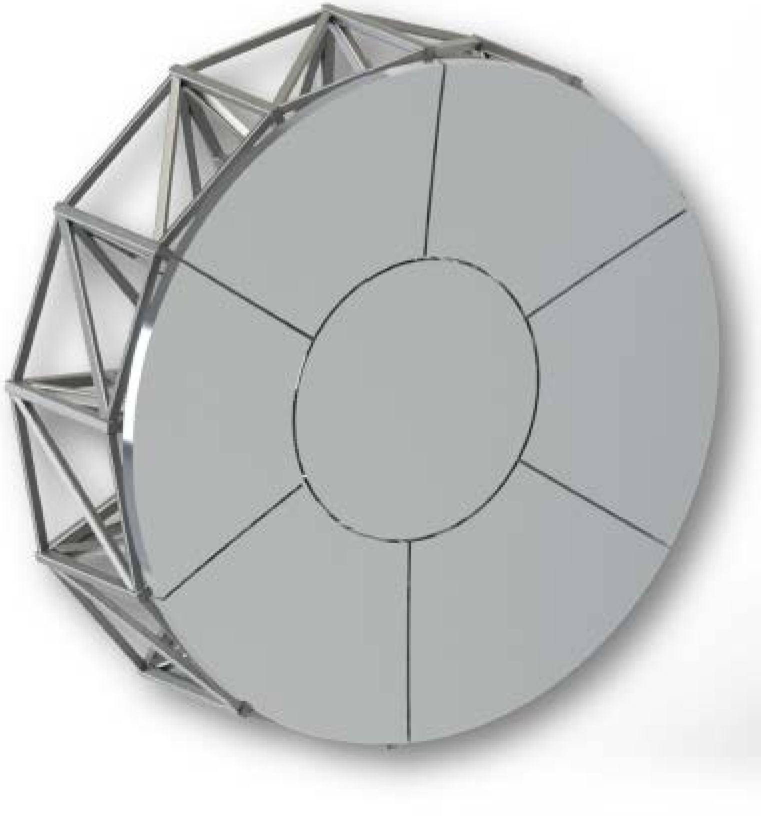
- 2018: University of Hamburg funding (500 k€) for the first prototype, with a 2.4-m reflector, a 12 – 18 GHz receiver, and a 4GHz DBBC.
- 2018: Proposal for a DFG Research Unit, seeking funding for BRASS-6.
  -- currently under review. If funded:
  2020-23: A double chamber BRASS-6 setup for Band 1 (~900 k€)
  2023-26: Detector extensions to Bands 2-4 (~800 k€)
- 2023: Seek funds for BRASS-100 (~8M€), through Large Instrumentation Programs of the DFG and MPG (or other funding sources)



BRASS-6: 2020-2023

- A two-chamber, 6m^2 setup, with two 2-m reflectors.
- Operating at 18 – 32 GHz band, with 4 GHz bandwidth (DBBC3).
- Tsys = 40 K.
- B ~ 0.8 T.
- A single chamber prototype is planned to be constructed in 2019-20, operating only for hidden photon DM searches.





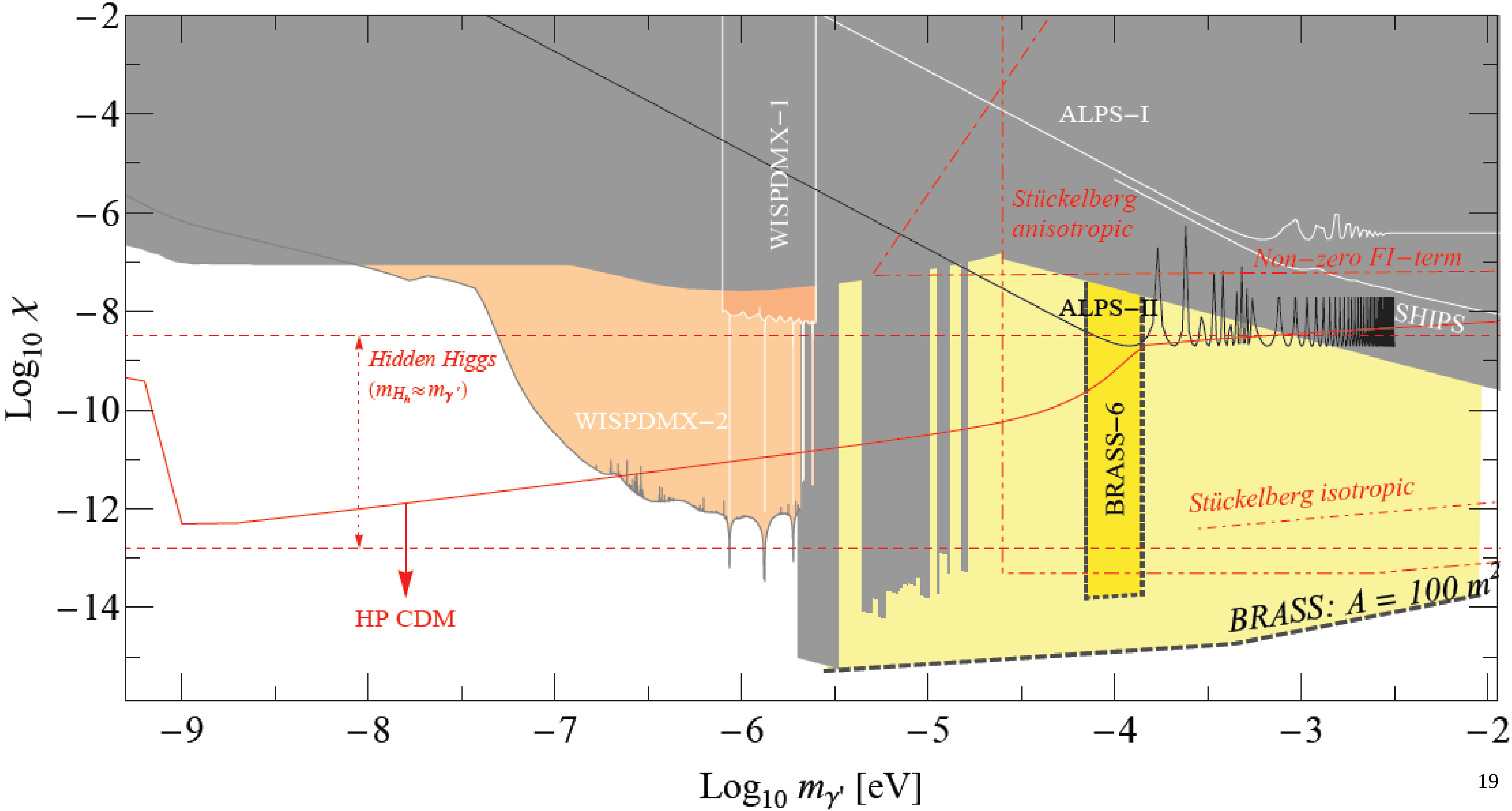
VERTEX ANTENNENTECHNIK GmbH
A GENERAL DYNAMICS COMPANY

BRASS Prototype

- Single chamber prototype to operate at 12-18 GHz. Stationed in a shielded laboratory at the UHH.
- 2.4 m reflector is installed.
- DBBC3 backend designed and manufactured at MPIfR & HatLab
- Frontend and receiver under construction at MPIfR. Expected in 2020/Q1.
- Conversion surface is under final design. A 40x40 cm, 1.4T Halbach array prototype is being ordered for performance tests.
- Planning to carry out initial hidden photon DM searches in the second half of 2020.

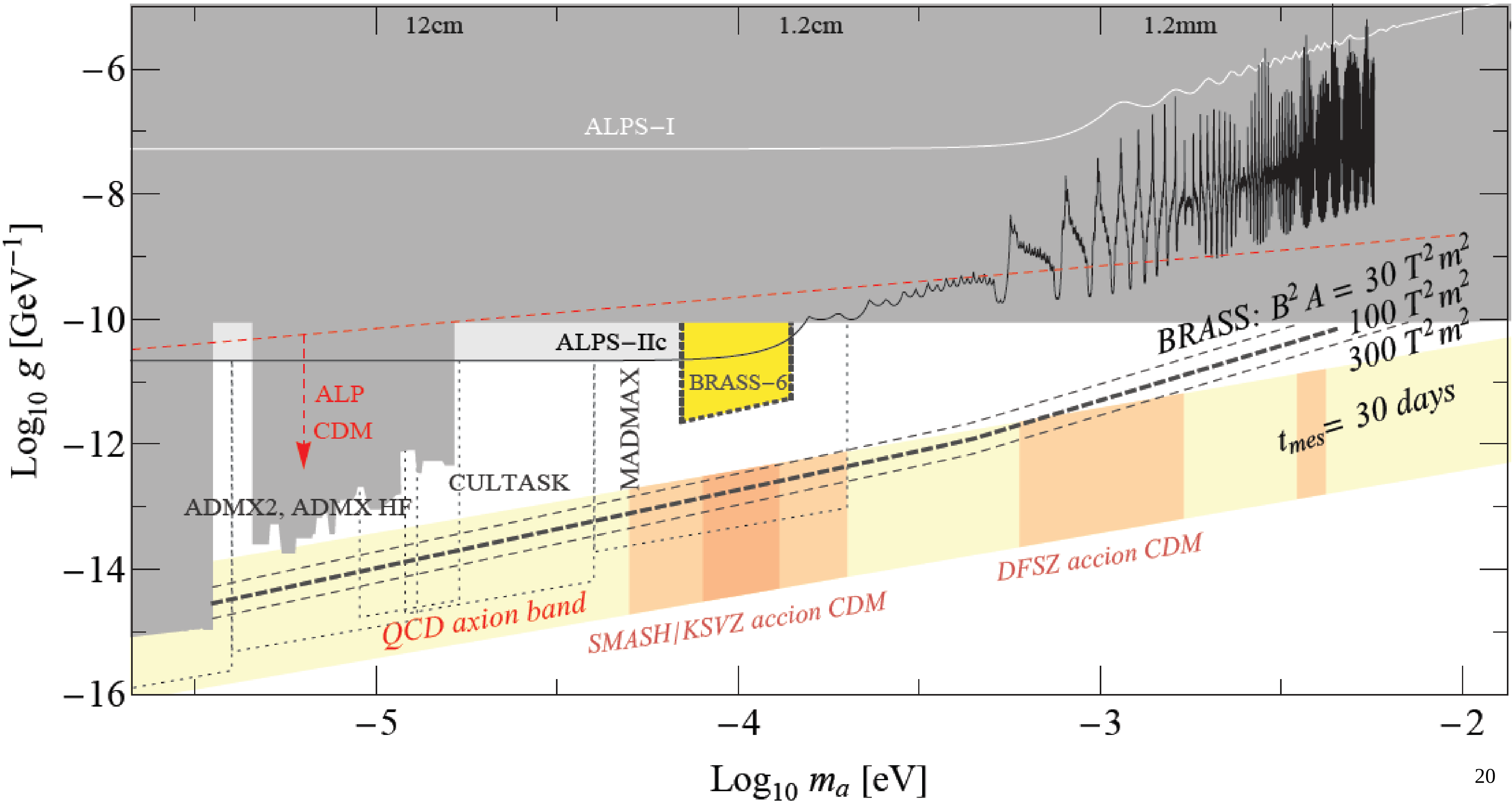
BRASS on Hidden Photon Dark Matter

- BRASS: Assuming one month runs at 4K and 5$h\nu$ detection sensitivity.
  BRASS-6: T_{sys} = 40 K, Band 1: 18-32 GHz.



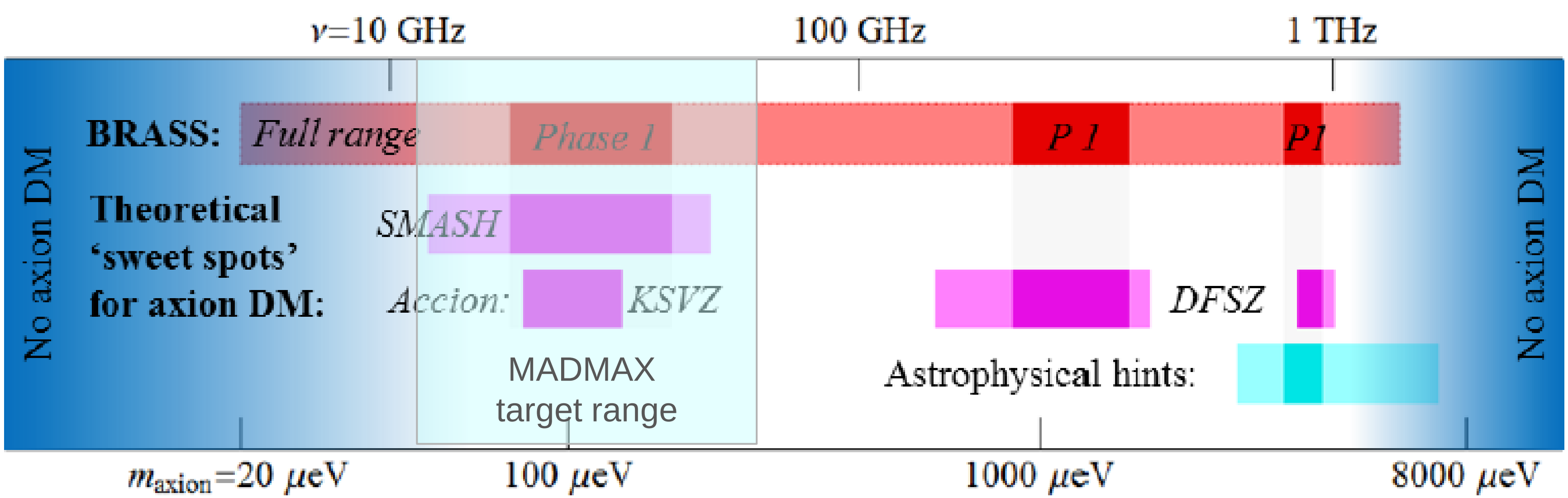
BRASS on Axion/ALP Dark Matter

- BRASS: Assuming one month runs at 4K and 5$h\nu$ detection sensitivity.
  BRASS-6: T_{sys} = 40 K, Band 1: 18 – 32 GHz.



Potential Synergies

- BRASS is primarily an ultra broadband facility enabling ALP searches in the 70–4000+ μeV range, and potentially reaching axion sensitivity only at the latest stages of its operation.
- Benefiting strongly from radioastronomy developments for ALMA (mm and sub-mm receivers) and EHT (broadband signal recording).
- Overlap with MADMAX in backend technology for the Band 1.
- Overlaps in signal processing (to some extent) and analysis with any axion DM experiment employing heterodyne detection.



Summary

- BRASS provides an affordable and scalable setup for extended searches for axion/ALP and hidden photon DM in the 20 – 1000 GHz range.
- In this capacity, BRASS will establish a long-term *facility* for WISP dark matter searches.
- Sensitivity will be an issue for QCD axion searches over the entire range. Will have to be addressed by employing a better tehcnology for permanent magnets or with multiple chambers.