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COST Action - WG4
25.05.23

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Le Hoang Nguyen for **BRASS** collaboration.
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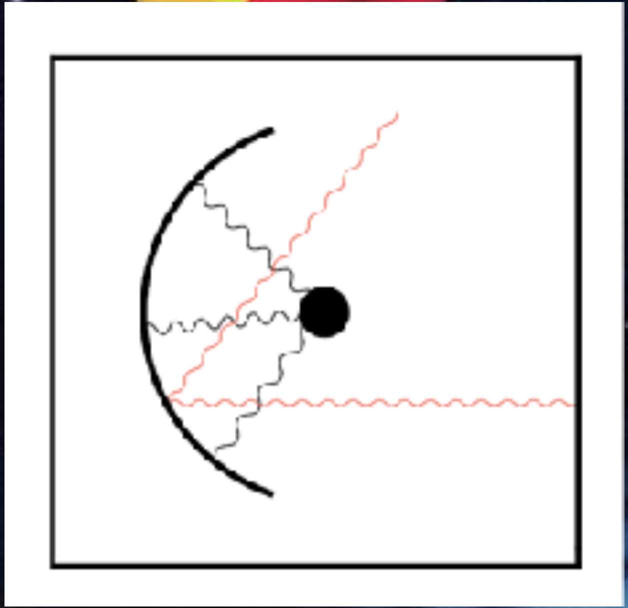
BRASS-p Search for WISPy Dark Matter

Contents:

- Broadband dark matter search with dish antenna.
- BRASS-p Setup and calibration
- Hidden Photon Search
- Axion/ALPs search with BRASS-p

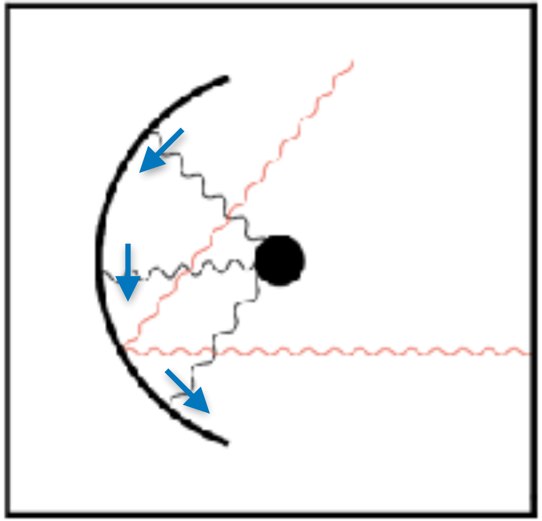
Setup of BRASS-p Experiment in University of Hamburg

Broadband dark matter search with dish antenna.



- Horns et al. 2013

Theoretical Foundation



Dish Antenna Search for Light Dark Matter

Hidden Photon

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

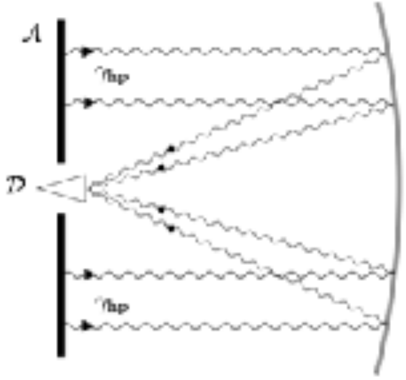
Axion/ALPs

$$g_{\phi\gamma\gamma,\,{\rm sens}} = \frac{3.6 \times 10^{-8}}{\rm GeV} \left(\frac{5\,{\rm T}}{\sqrt{\langle|{\bf B}_{||}|^2\rangle}}\right) \left(\frac{P_{\rm det}}{10^{-28}\,{\rm W}}\right)^{\frac{1}{2}} \left(\frac{m_\phi}{\rm eV}\right) \left(\frac{0.3\,{\rm GeV/cm^3}}{\rho_{\rm DM,halo}}\right)^{\frac{1}{2}} \left(\frac{1\,{\rm m^2}}{A_{\rm dish}}\right)^{\frac{1}{2}},$$

Horns et al. 2013

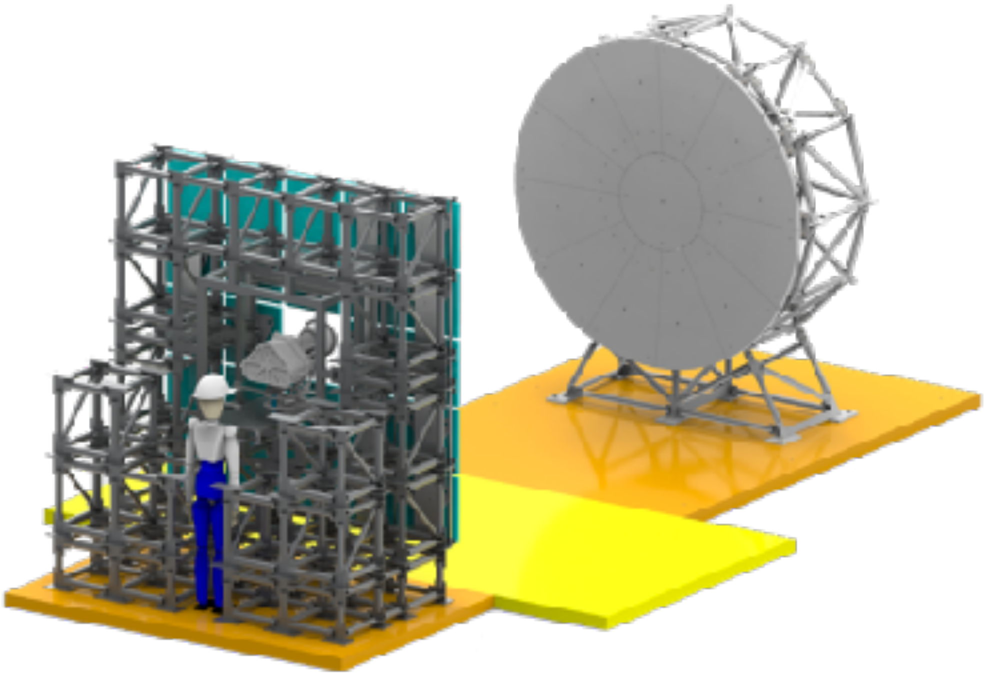
BRASS

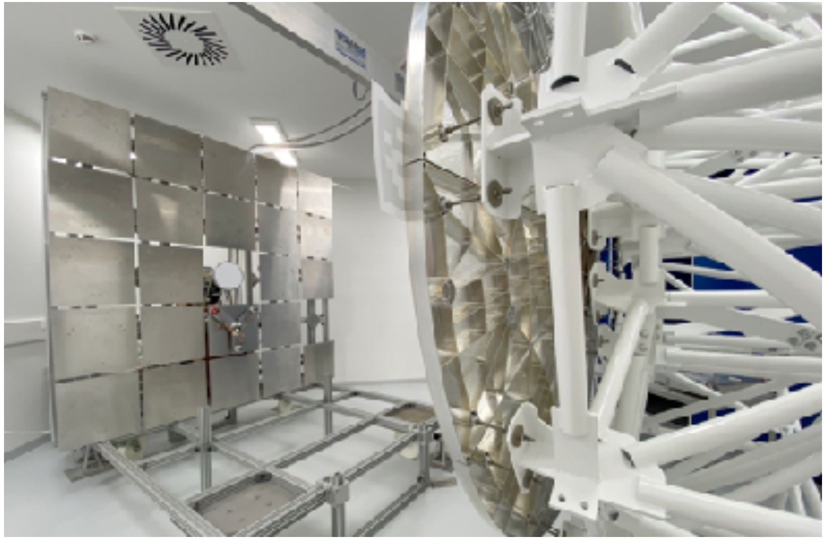
- **Broadband sensitivity to a large parameter space and resonant enhancement is compensated by the large surface area.**
- **Broadband Radiometric Axion SearcheS (BRASS)**
    - A parabolic mirror (collective mechanism)
    - Flat conversion panels (w/magnets) (signal generation)
    - Front and backend systems for receiving and processing the signal (signal collecting)



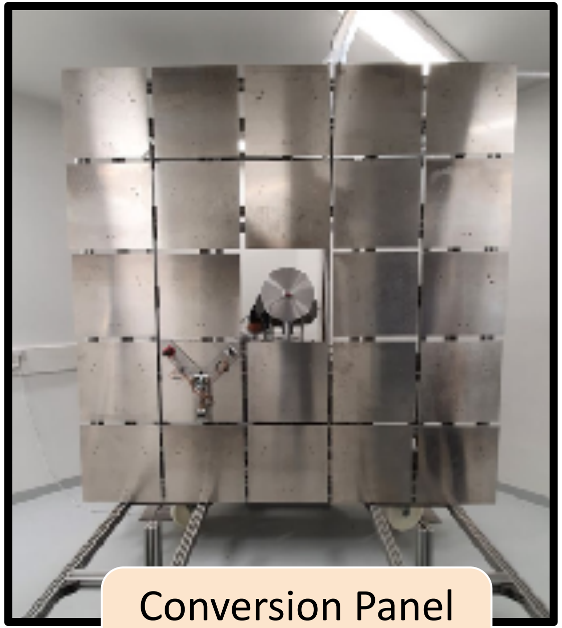
Prototype: BRASS-p

BRASS-p Setup

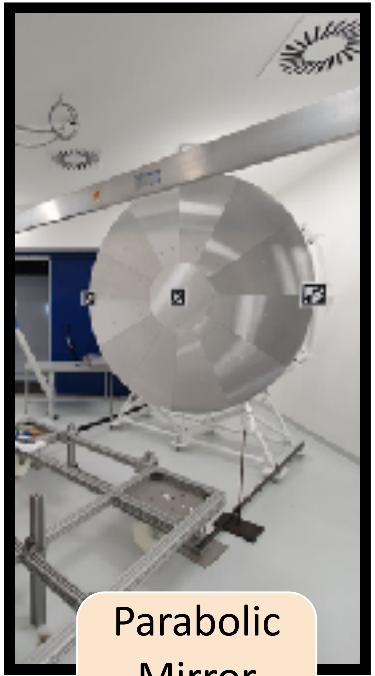




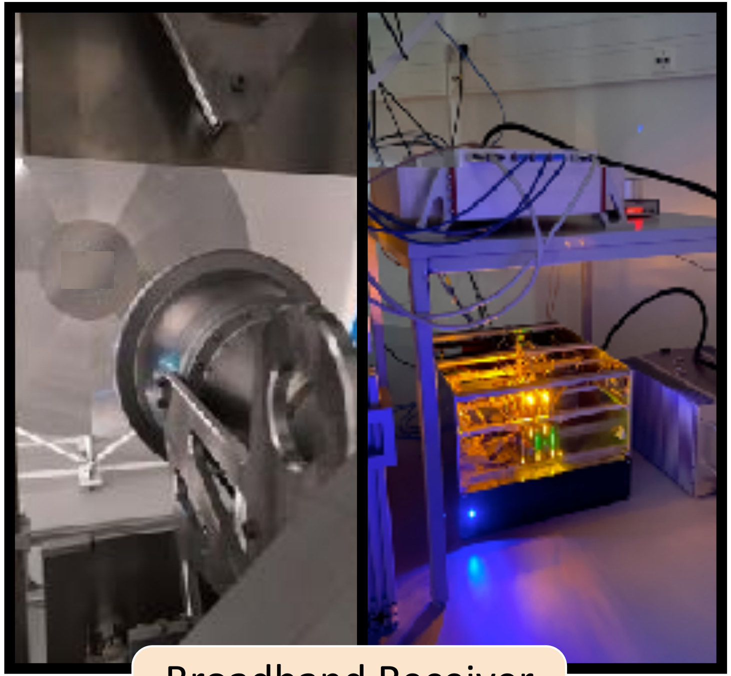
Key Components



Conversion Panel
(24 x 0.25m²)

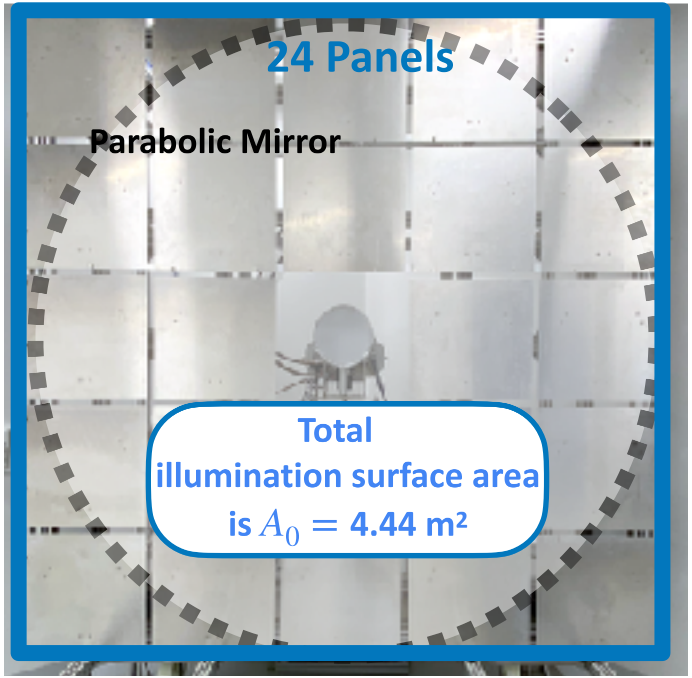


Parabolic
Mirror
d = 2.5m

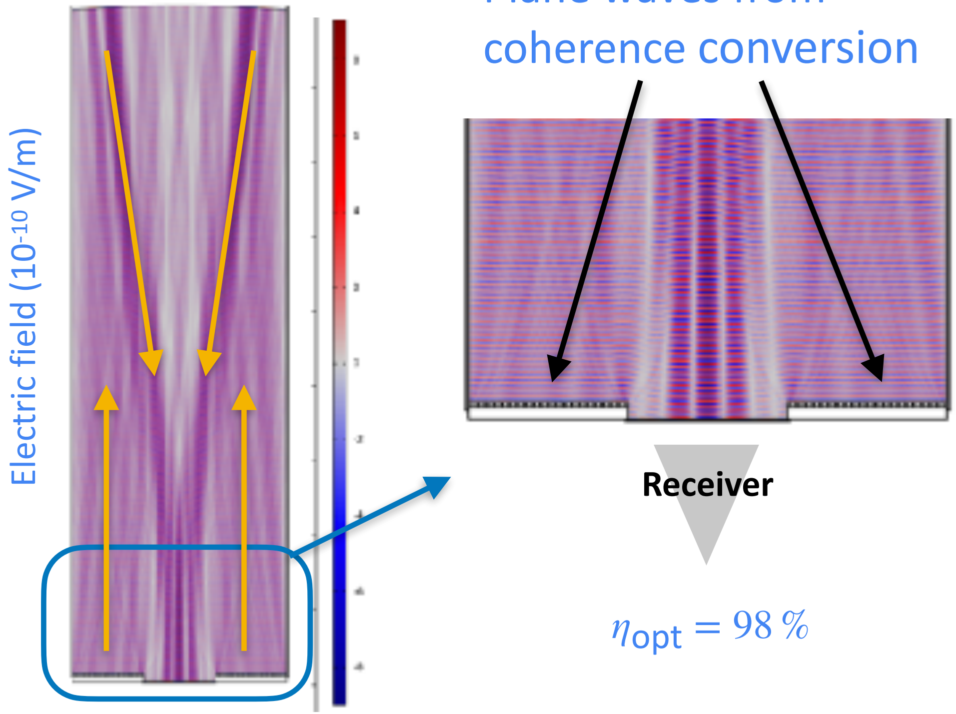


Broadband Receiver
(12-18 GHz)

Conversion Panels

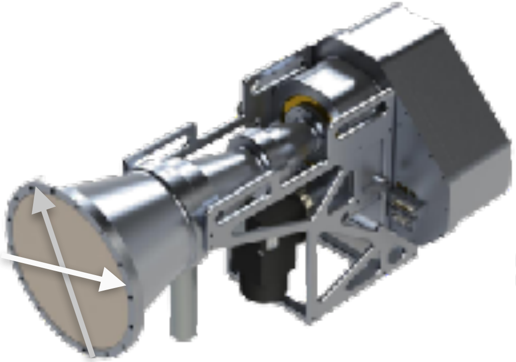


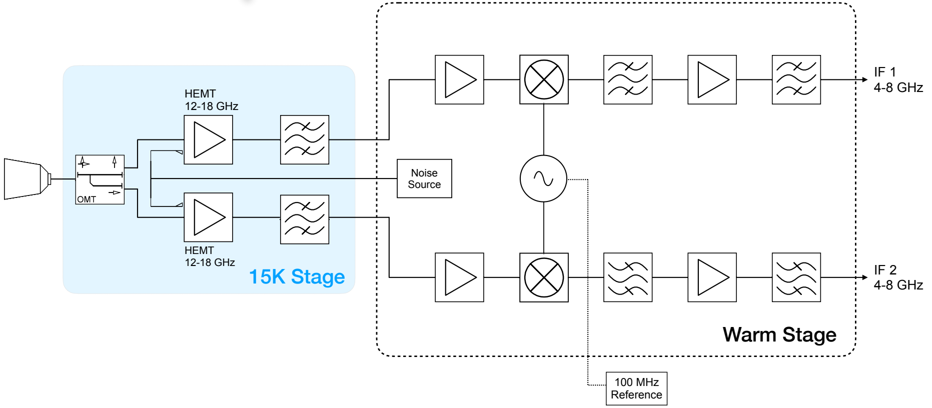
Plane waves from coherence conversion



Frontend: Ku-Band Receiver

- Broadband 12 to 18 GH to IF 4-8 GHz.
- 3-LNA-chain with 1st stage operated at approx 10 K
- Two polarizations outputs for DM signal study/rejection.

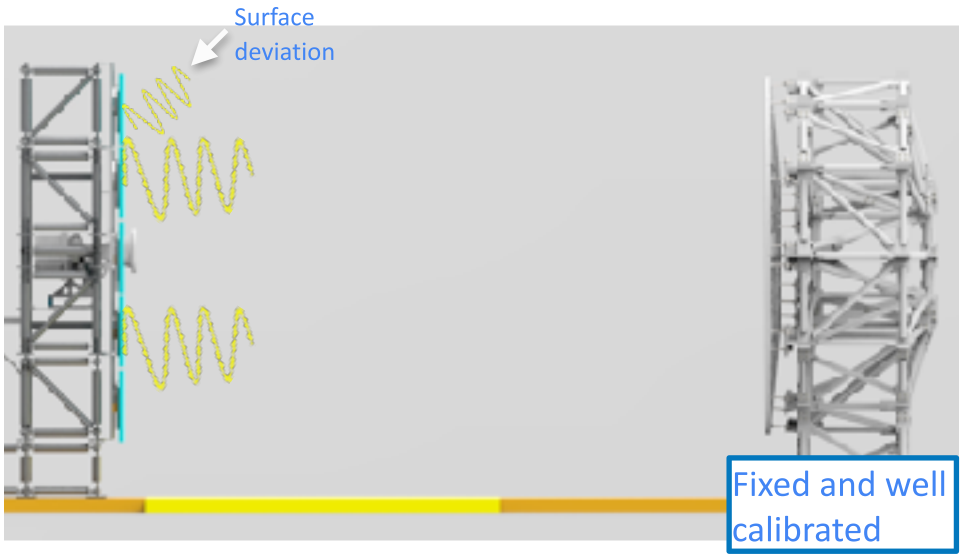




Optical Calibration and Coupling Efficiency

Effective Area = Projected Area x η_A

$$\eta_A = \eta_{sf} \cdot \eta_{il} \cdot \eta_{sp} \cdot \eta_{opt} \cdot \eta_{ph}$$



1. High surface deviation → reducing plane wave formation (η_{sf})
2. Bad antenna design → reducing illumination and spillover efficiency ($\eta_{il} \cdot \eta_{sp}$)
3. Bad receiver positioning → reducing phase center coupling efficiency (η_{ph})

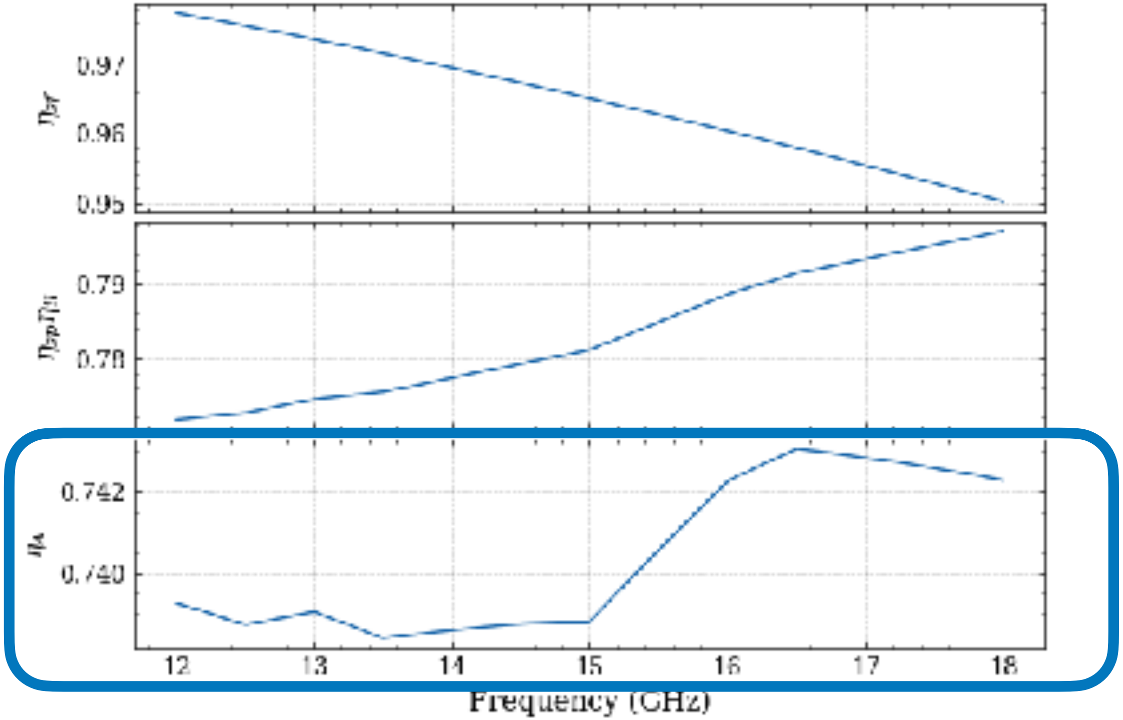
Optical Calibration and Coupling Efficiency

Parabolic mirror has $\sigma_s = 4 - 7\mu m$
Conversion area $\sigma_s = 0.3$ **mm**
(Ruze's Formula)

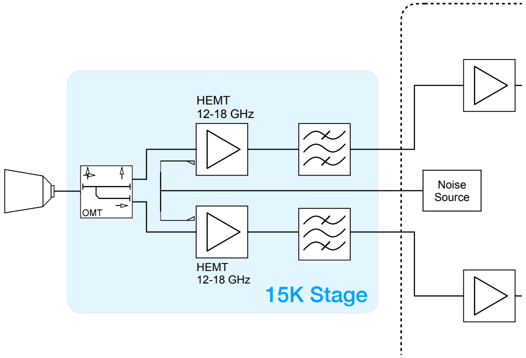
Optimized taper (-10dB) to D/f

$\eta_{\text{opt}} \approx 0.98$

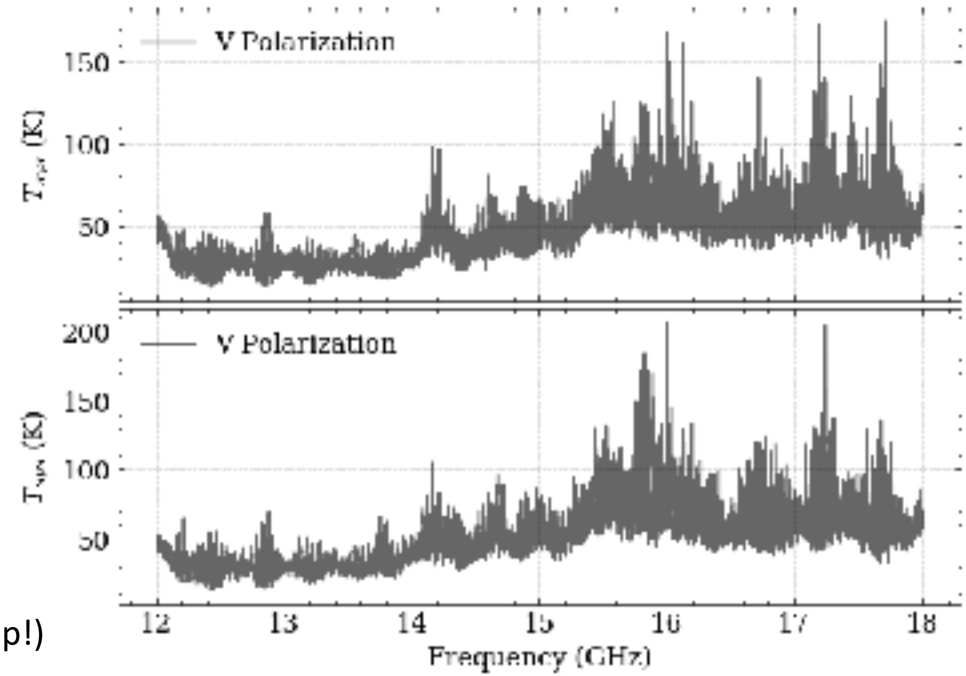
$\delta_{fs} < 0.1\text{mm} \ll \lambda_{\text{12-18 GHz}} -> \eta_{ph} \approx 1$



System Temperature



Using the calibration diode (14K)



Noise system is 2-4 times higher than T_rec

🤔 suspecting the environment

🤔 noise from 1st stage LNA (a circulator will help!)

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Digital Backend: 8 GS/S Realtime Processing

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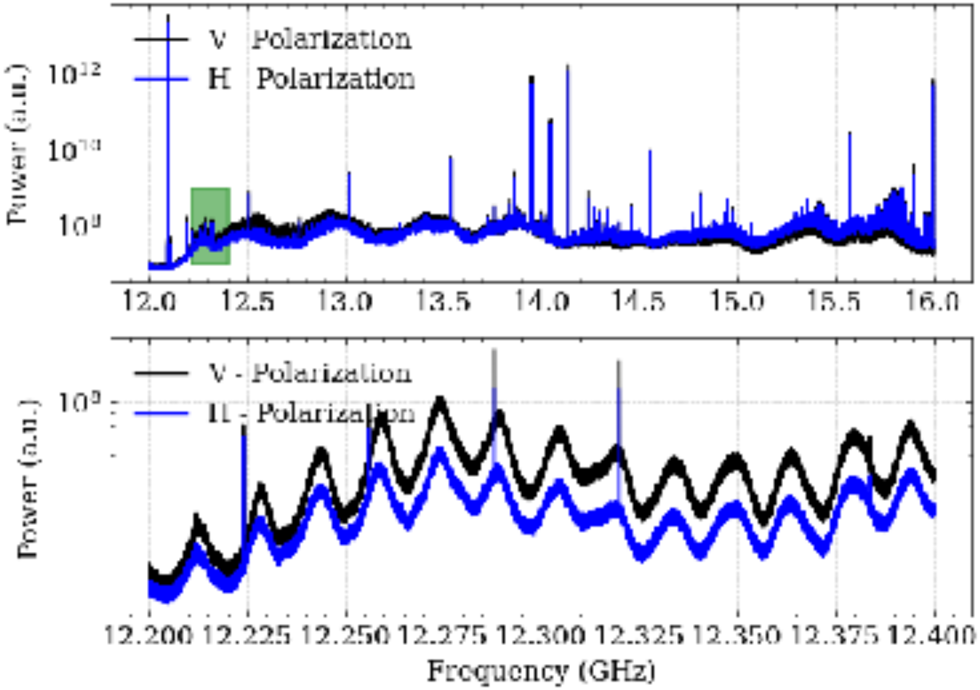
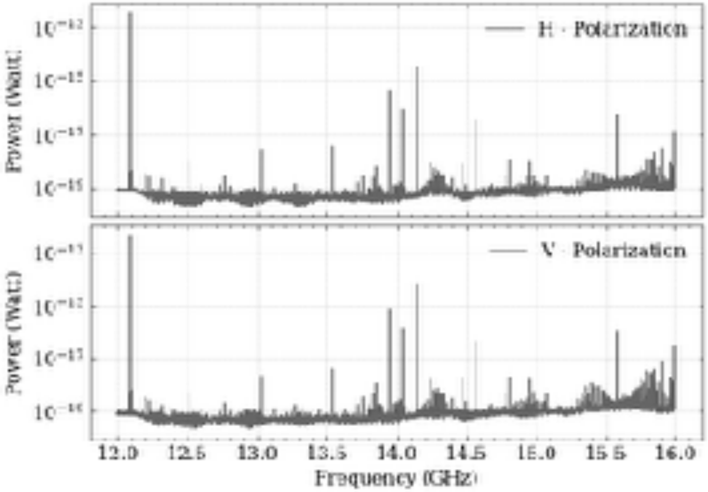
- Second down-conversion the signal from the receiver to a DC - 4 GHz IF range.
- 4 interleaved FPGA at 2 GSPS each digitizing the IF signal.
- Data is transferred to the acquisition PC and temporally stored on disc. Following by the interleaving and FFT.
- GPU powered FFT produces high resolution (up to 25 Hz) with real-time post processing.

BRASS-p standard spectrum



- 19.8 second of time data.
- $\Delta\nu = 125$ Hz → averaged of 2475 spectrums
- 4 GHz IF bandwidth



BRASS-p standard spectrum

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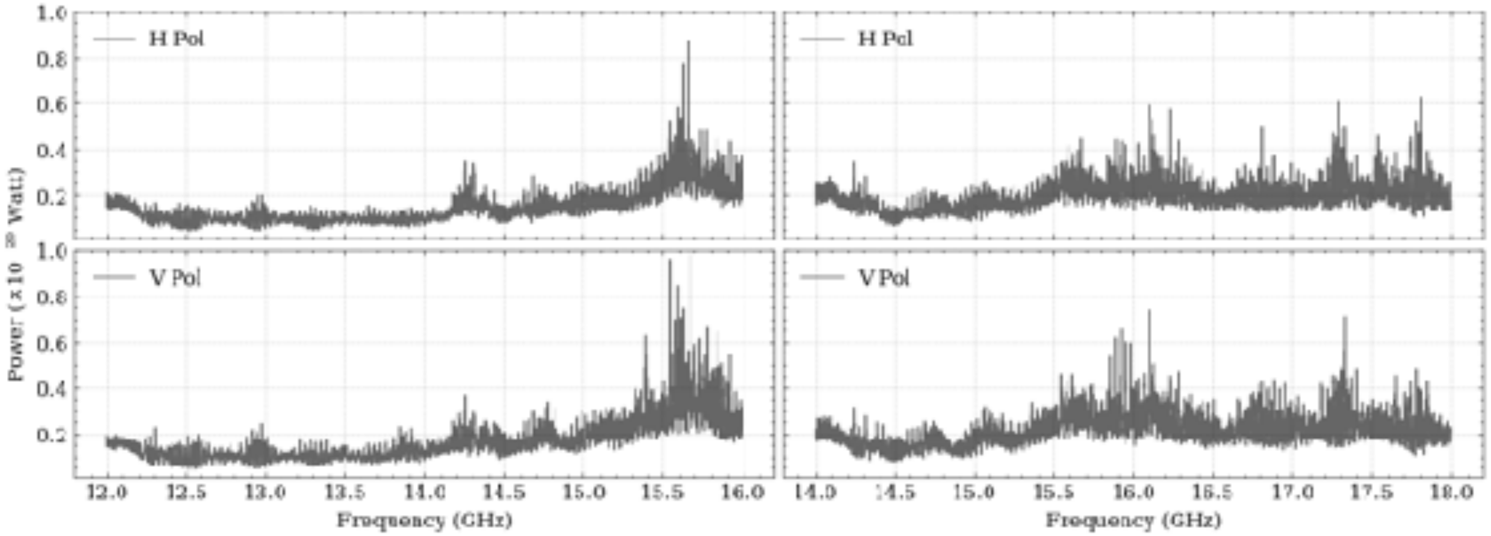

Lowest detectable power within a 125 Hz channel

Important for transient stream/tidal dark matter signal.

Lowest det power is 10^{-21} Watt over 12-16 GHz/14-18 GHz in only 19.8 sec

Hidden photon dark matter search

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Hidden photon dark matter search

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	SR1a	SR1b
Frequency band:	12-16 GHz	14-18 GHz
Number of polarization channels:	2	2
Spectral resolution:	125 Hz	125 Hz
Starting date:	13 Nov 2022	24 Nov 2022
Ending date:	19 Nov 2022	2 Dec 2022
Number of spectra collected:	9998	12012
Total measurement time:	54.989 hours	66.096 hours

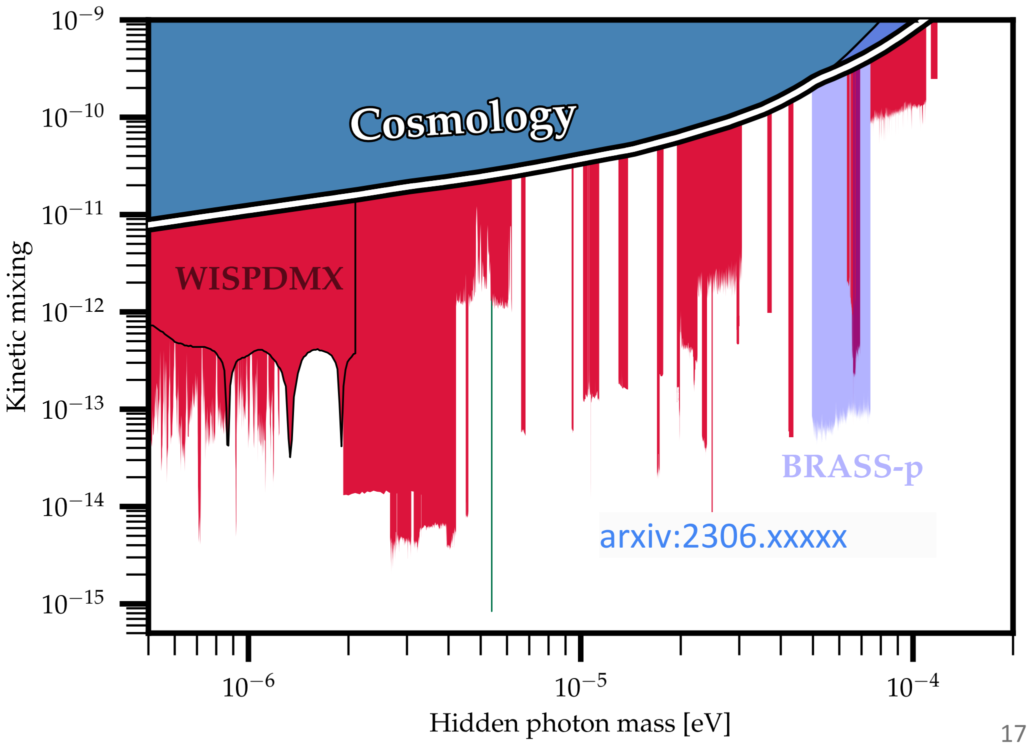
Lowest det pow of 10^{-23} Watt

Maxwellian DM span over multiple channels

$$\chi(\nu) = 3.2 \times 10^{-14} \left(\frac{\sigma_{\rm det}(\nu) N_{\rm ch}(\nu)^{-1/2}}{10^{-23}\ \rm W} \right)^{\frac{1}{2}} \times \left(\frac{0.3\ \rm GeV/cm^3}{\rho_{\rm DM}} \right)^{\frac{1}{2}} \left(\frac{1\ \rm m^2}{A_{\rm eff}} \right)^{\frac{1}{2}} \left(\frac{\sqrt{2/3}}{\alpha} \right)$$

$A_0 \cdot \eta_A$

$\sqrt{2/3}$



👉[github.com/cajohare/AxionLimits]👍

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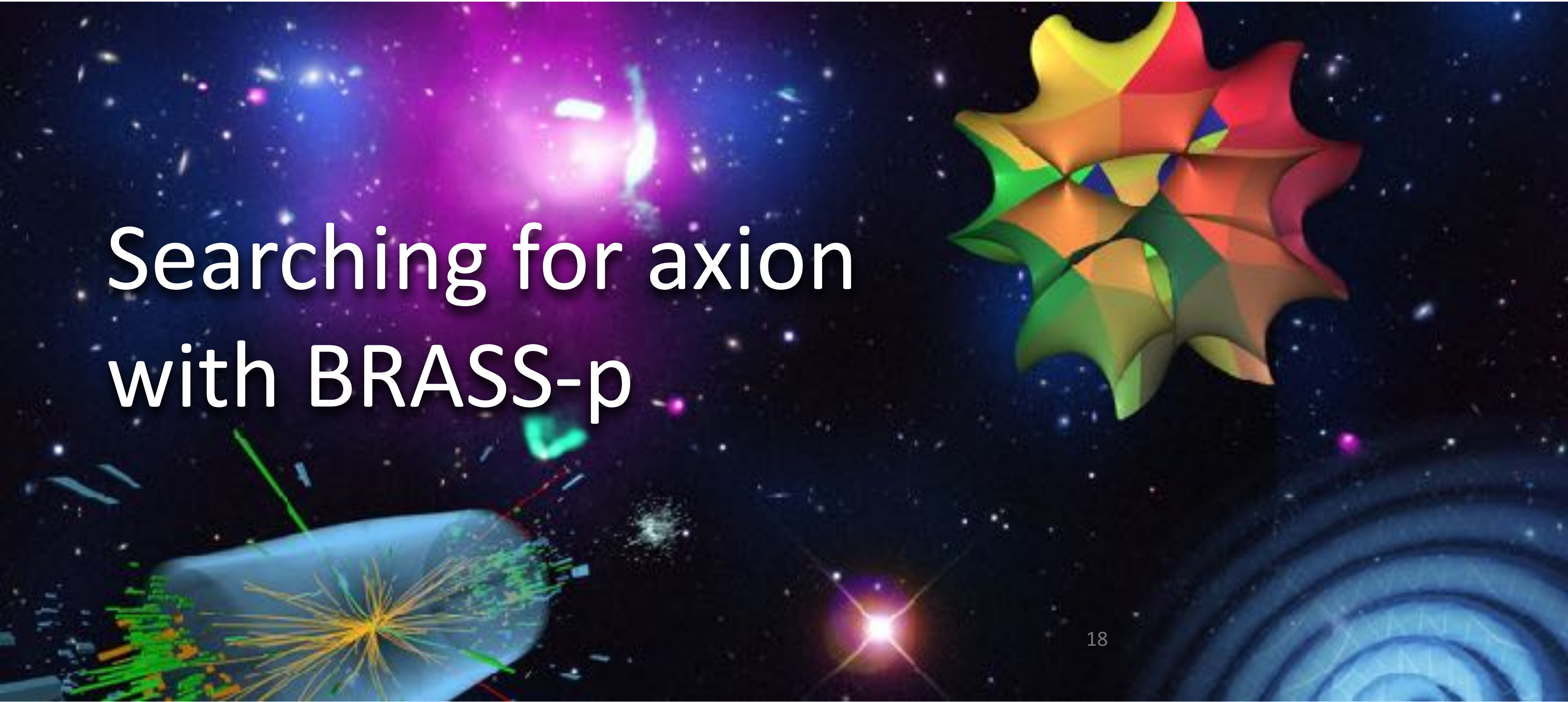

Searching for axion with BRASS-p

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Permanent Magnet Panel for Axion/ALPs Search

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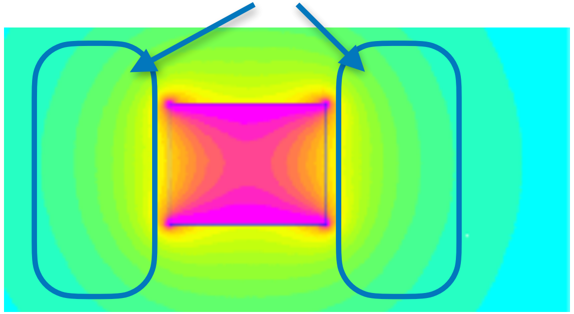
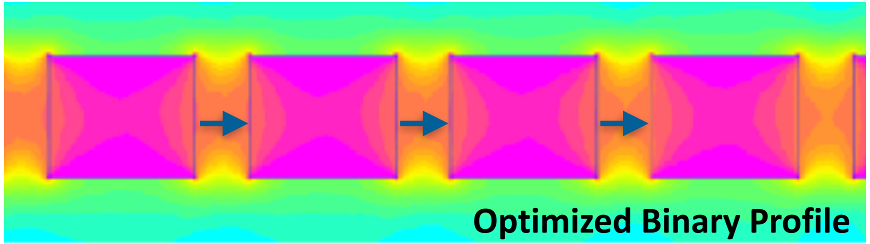
Field is not concentrated



Single Magnet Cube

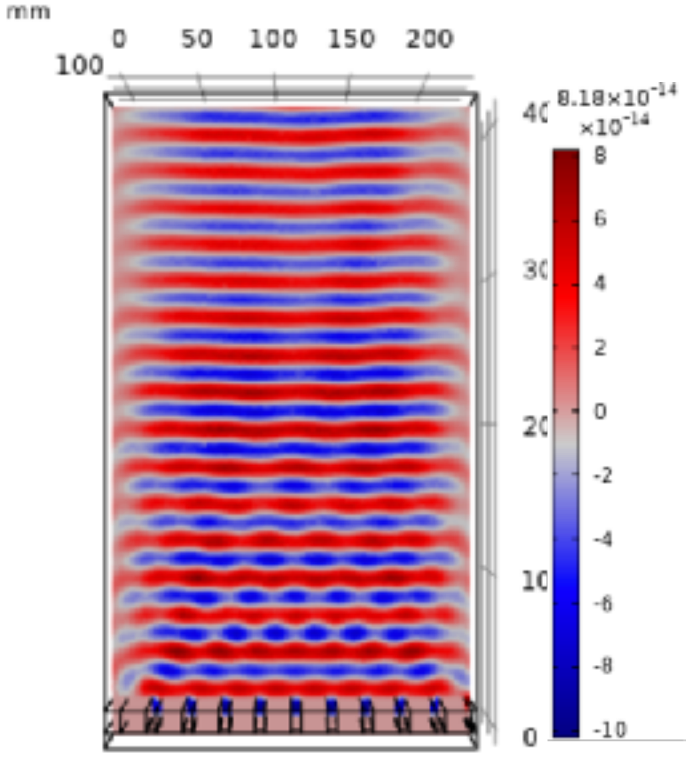


Optimized Binary Profile

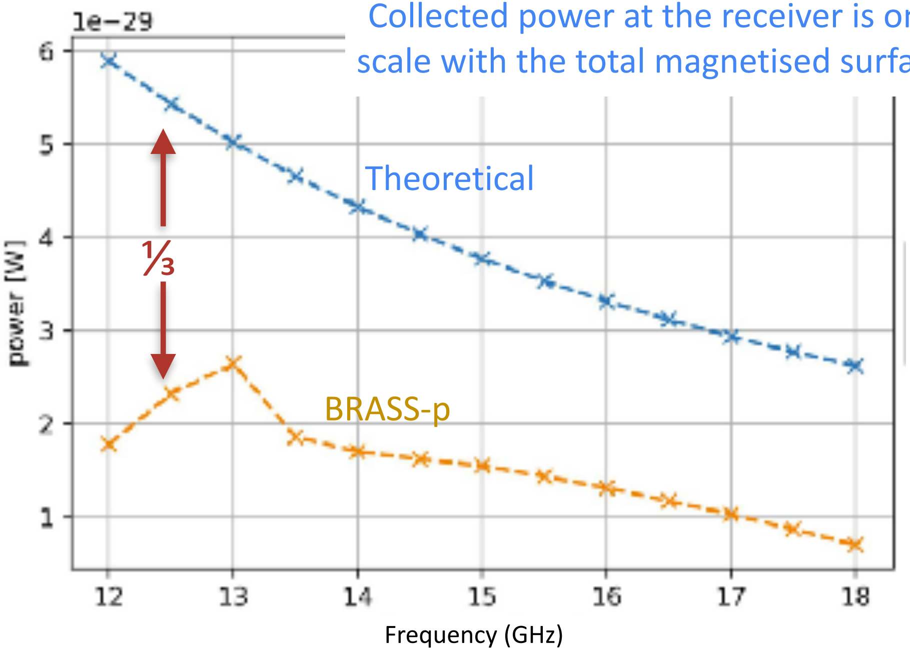
Very much affordable!

Averaged horizontal field strength is approx 0.9 Tesla

Converted Radiation Simulation

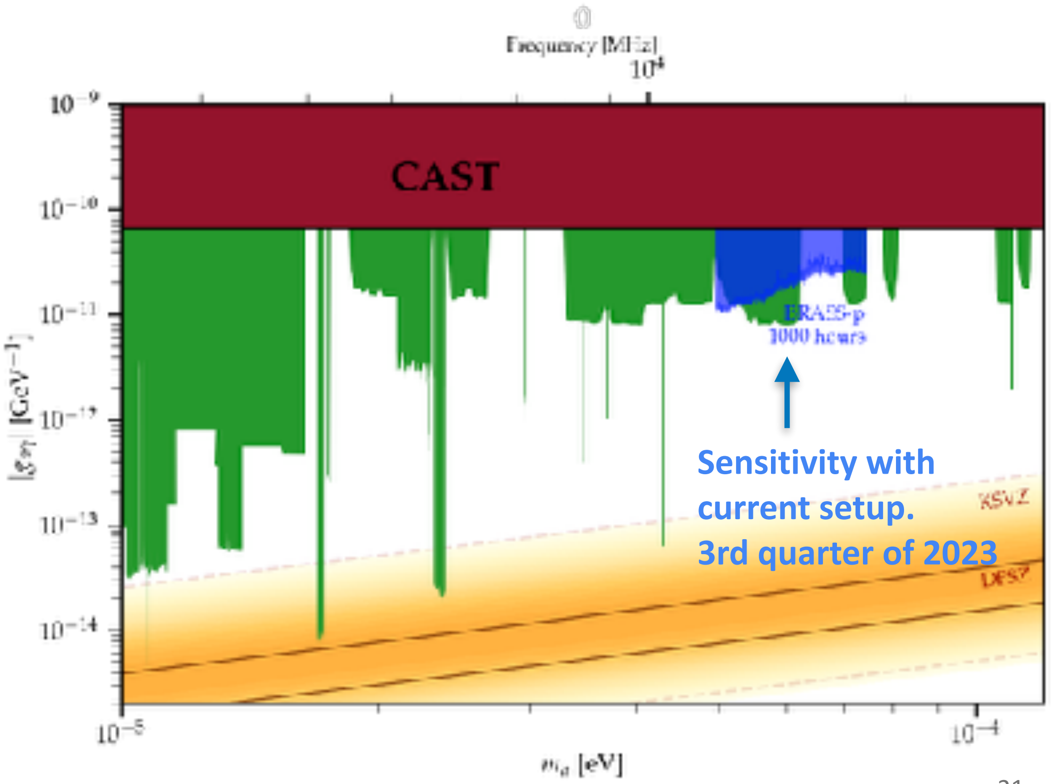


Collected power at the receiver is only scale with the total magnetised surface.



Axion/ALPs Search

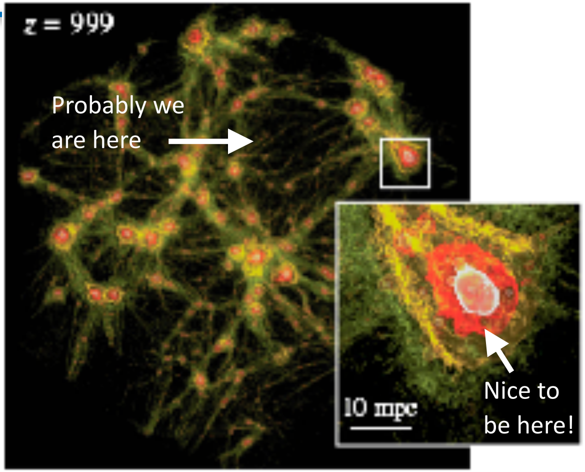
$$g_{a\gamma\gamma} = \frac{3.6\times10^{-8}}{\text{GeV}}\left(\frac{\sigma_{\text{det}}(\nu)N_{\text{ch}}(\nu)^{-1/2}}{10^{-23}\ \text{W}}\right)^{\frac{1}{2}}\left(\frac{5\ \text{Tesla}}{B_{\text{ex}}}\right)$$
$$\times\left(\frac{m_a}{\text{eV}}\right)\left(\frac{0.3\ \text{GeV/cm}^3}{\rho_{\text{DM}}}\right)^{\frac{1}{2}}\left(\frac{1\ \text{m}^2}{A_{\text{eff}}}\right)^{\frac{1}{2}}$$



Road to QCD Axion for BRASS

- Axion dark matter density is considered stable
  - Thermal Virialised dark matter following Maxwellian profile ($\rho_{stdDM} \approx 0.45$ GeV/cm^3)
  - Solar system with in the minivoid ($\rho_{\text{minivoid}} \approx 0.075\rho_{stdDM}$)

→ Stronger magnet panel (2-3 Tesla), larger surface area (x 10), dielectric implementation.



EGGEMEIER et al. PRD 107, 083510 (2023)

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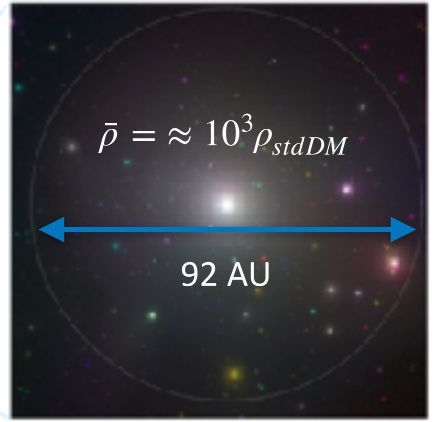
Road to QCD Axion for BRASS

- **Axion dark matter density is transient and modulated**
  - **Minicluster/axion stars colliding** ($\rho_{\text{minicluster}} \approx (10^2 - 10^8)\rho_{stdDM}$)
  - **DM Stream/tidal/seasonal gravitation focusing**

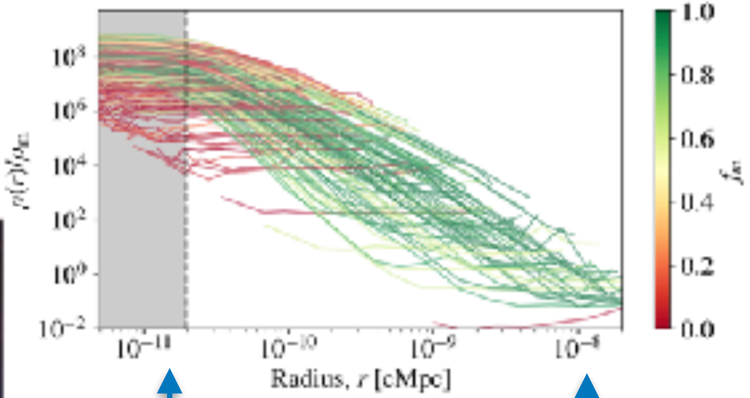
Signal has narrow width - $(10^{-9} - 10^{-8})m_a$ and transient.

Stream: Bijunath R. Patla et al 2014 ApJ 780 158, Frère et. al Phys. Rev. D 77, 083005, Tinyakov JCAP 01 (2016) 035, Kryemadhi arXiv:2210.07367. **Axion Quark Nugget**: Zhitnitsky MPLA Vol.36, No.18, 2130017 (2021)



Eggemeier et al. Phys. Rev. Lett., 125.4 (2020)

v⊙ = 0.2 mpc/year



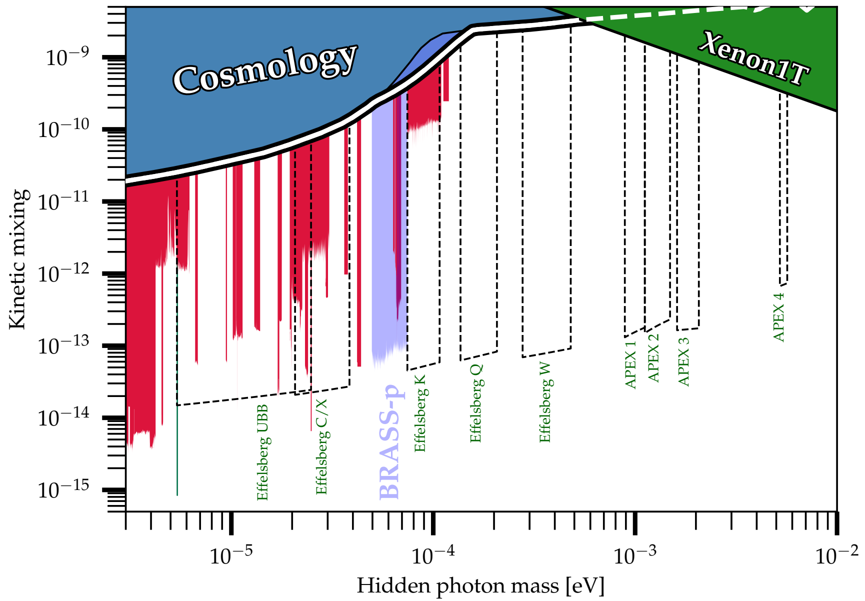
High DM density But colliding time is only 18 days

this is 50 years

Ellis et. al 10.1103/PhysRevD.106.103514

Future Development and Conclusion

- BRASS is the synergy between radio astronomy and WISPs direct search.
- State-of-art receiver and digitizer (4 GHz, 125 Hz)
- Sensivity to various scenarios of WISPs (non-polarization HP, polarized HP, Thermal Virialized DM, Transient DM) during one instance of acquistion.
- Future
    - Mounting magnet panels for ALPs search (2023)
    - Implementation of dielectric configuration for magnet panel.
    - Different frequency band with different receiver + next gen digitizer (16 GHz)



Sensitivity of the BRASS-p (probably exclusion limit too) with the other future implementation of available receiver in MPIfr.

Thank you for your attention