Axion Haloscope Astronomy

Stefan Knirck,
Fermi National Accelerator Laboratory
Fermilab

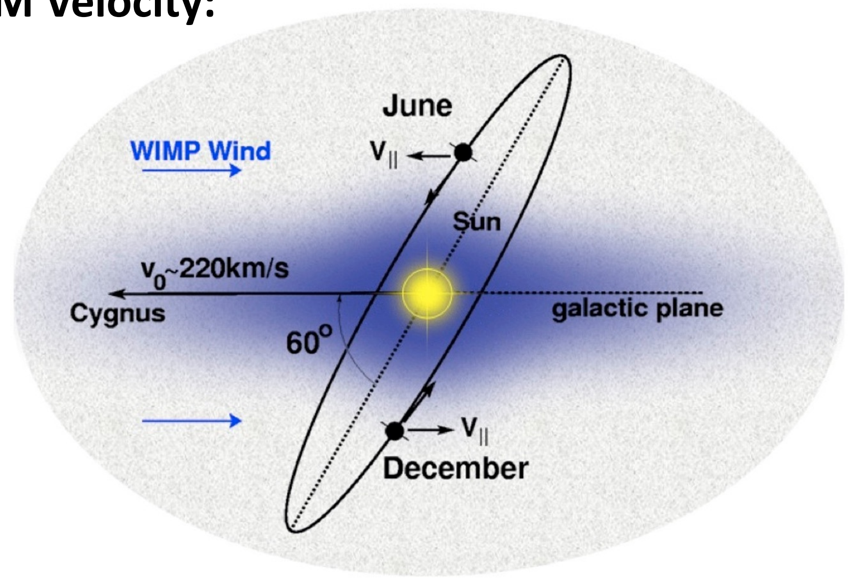
member of ADMX, BREAD and MADMAX

MS Office Stock Photo

Axion Haloscopes = Axion Telescopes

[M. Turner
Physical Review D 42.10 (1990): 3572.]

CDM Velocity:



[https://www.hep.ucl.ac.uk/
darkMatter/pictures/wind.jpg]

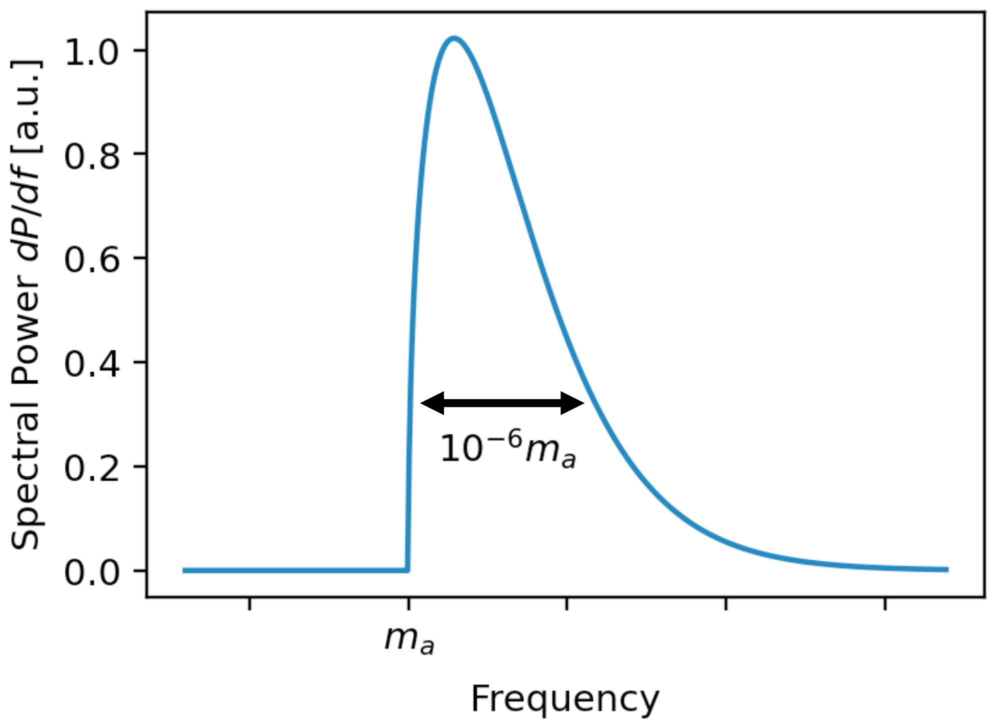
Standard Halo Model:

$$f(\boldsymbol{v}) = \frac{1}{(2\pi\sigma_v^2)^{3/2}} \exp\left(-\frac{|\boldsymbol{v}-\boldsymbol{v}_{\rm lab}|^2}{2\sigma_v^2}\right) \frac{\Theta\left(v_{\rm esc}-|\boldsymbol{v}|\right)}{N_{\rm esc}}$$

$$|\boldsymbol{v}_{\rm lab}| \sim 220\,{\rm km\,s^{-1}},\ \sigma_v \sim 156\,{\rm km\,s^{-1}}$$

DM velocity ~ $v \sim 10^{-3}c$

"Standard" Haloscope Signal Shape:



$$E = mc^2 + \frac{1}{2}mv^2$$

Axion Haloscopes = Axion Telescopes

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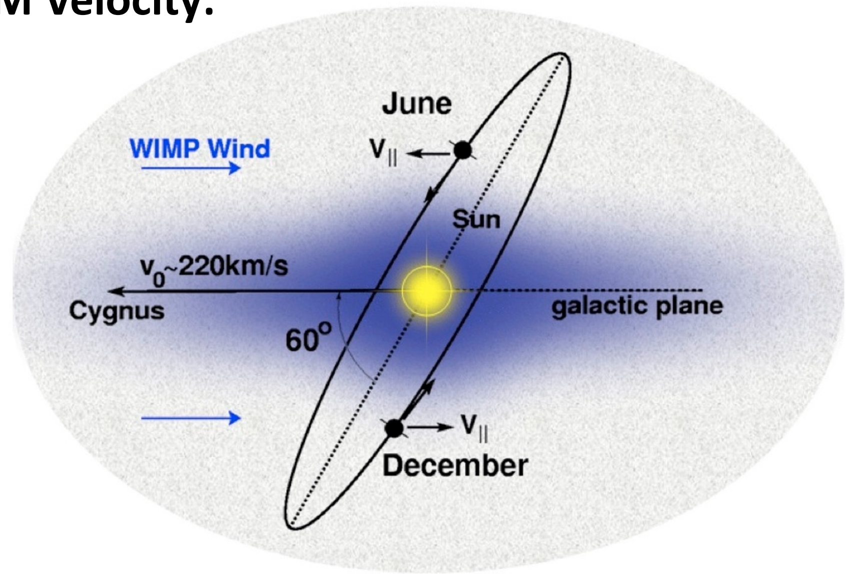
CDM Velocity:



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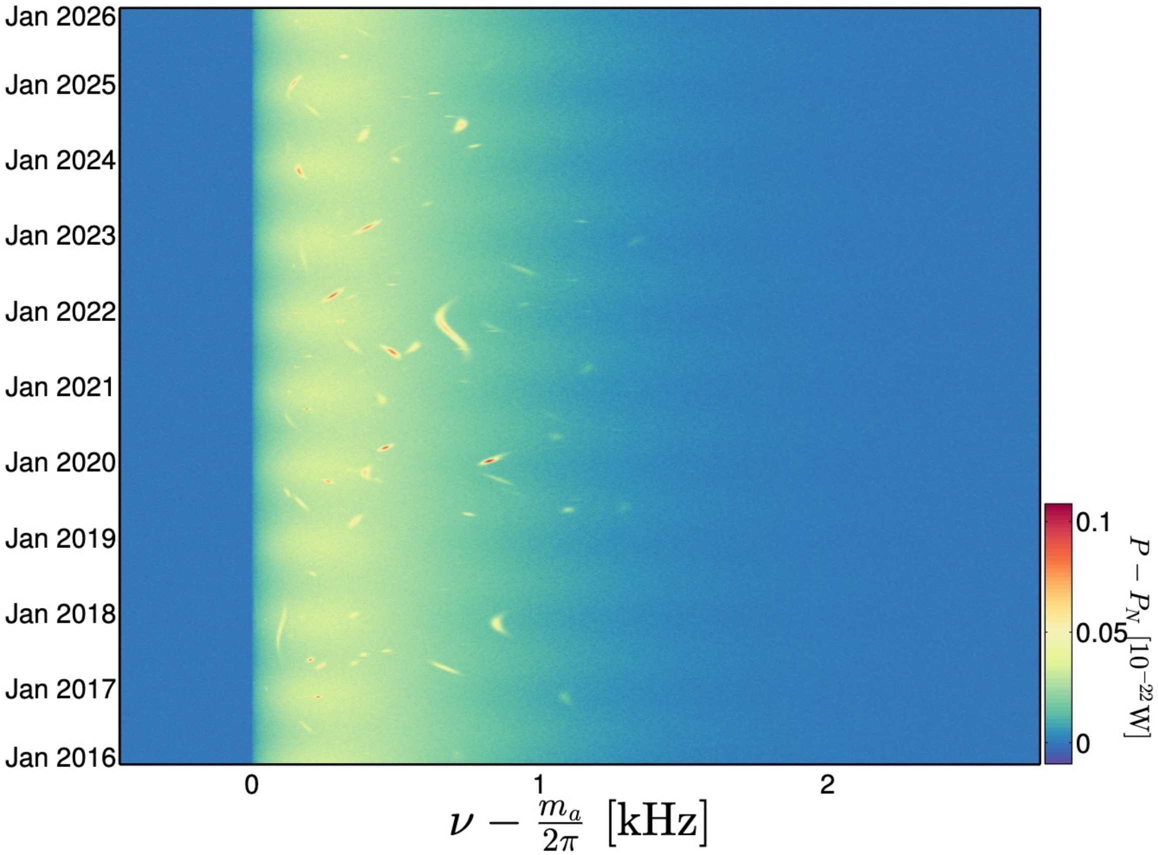
DM velocity $\sim v \sim 10^{-3} c$

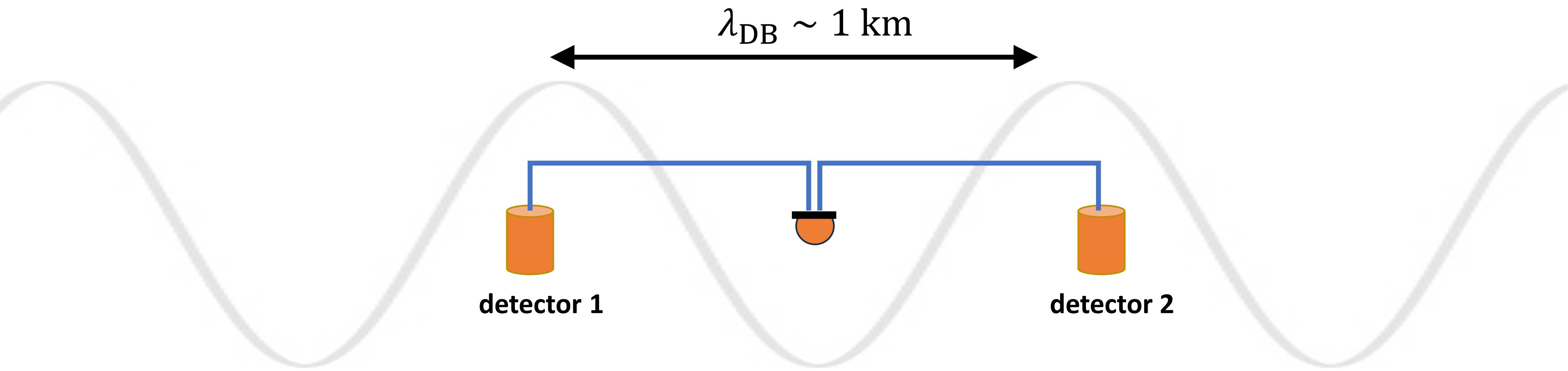
… with substructure:



[O'Hare et al.
arXiv:1701.03118]

Wave-like Dark Matter

$$\rho_a \sim 0.45\,\frac{\mathrm{GeV}}{\mathrm{cm}^3} \qquad \lambda_{\mathrm{DB}} \sim \frac{2\pi}{m_a v} \sim 1\,\mathrm{km}\left(\frac{1\mu\mathrm{eV}}{m_a}\right) \quad \rightarrow \quad \frac{\#\mathrm{particles}}{\lambda_{\mathrm{DB}}^3} \sim 10^{30}\left(\frac{1\mu\mathrm{eV}}{m_a}\right)^4$$

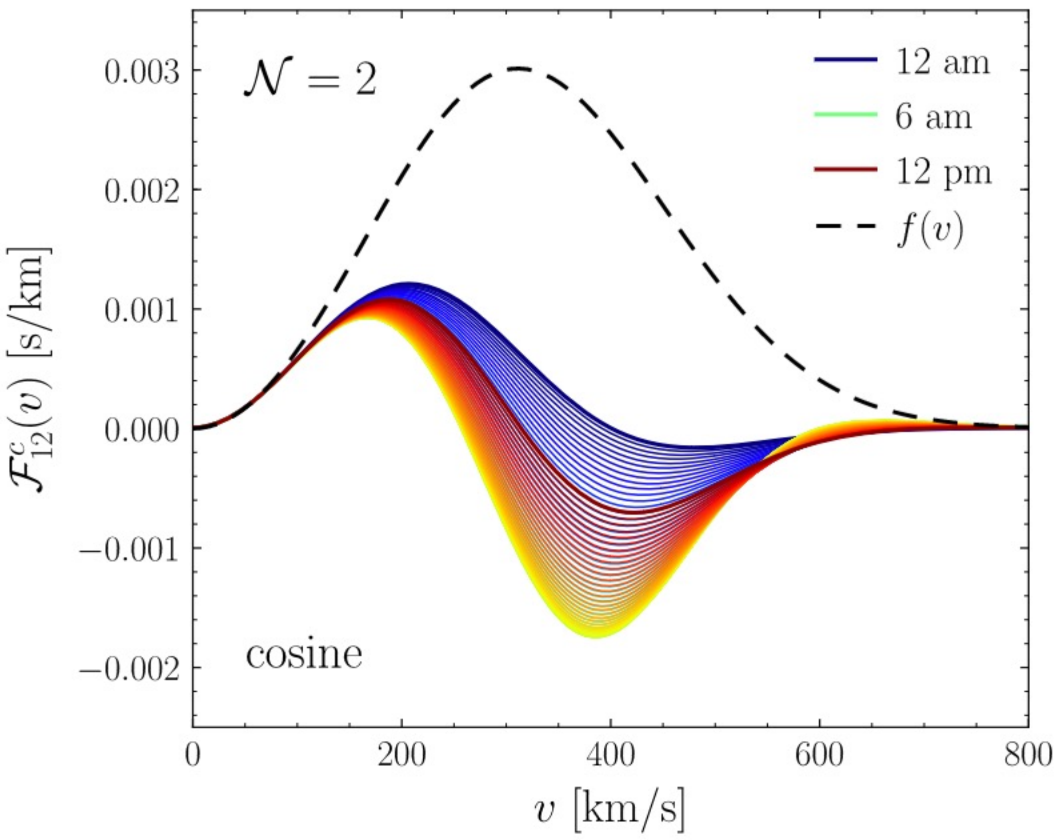


coherent detection → interferometry

Interferometry

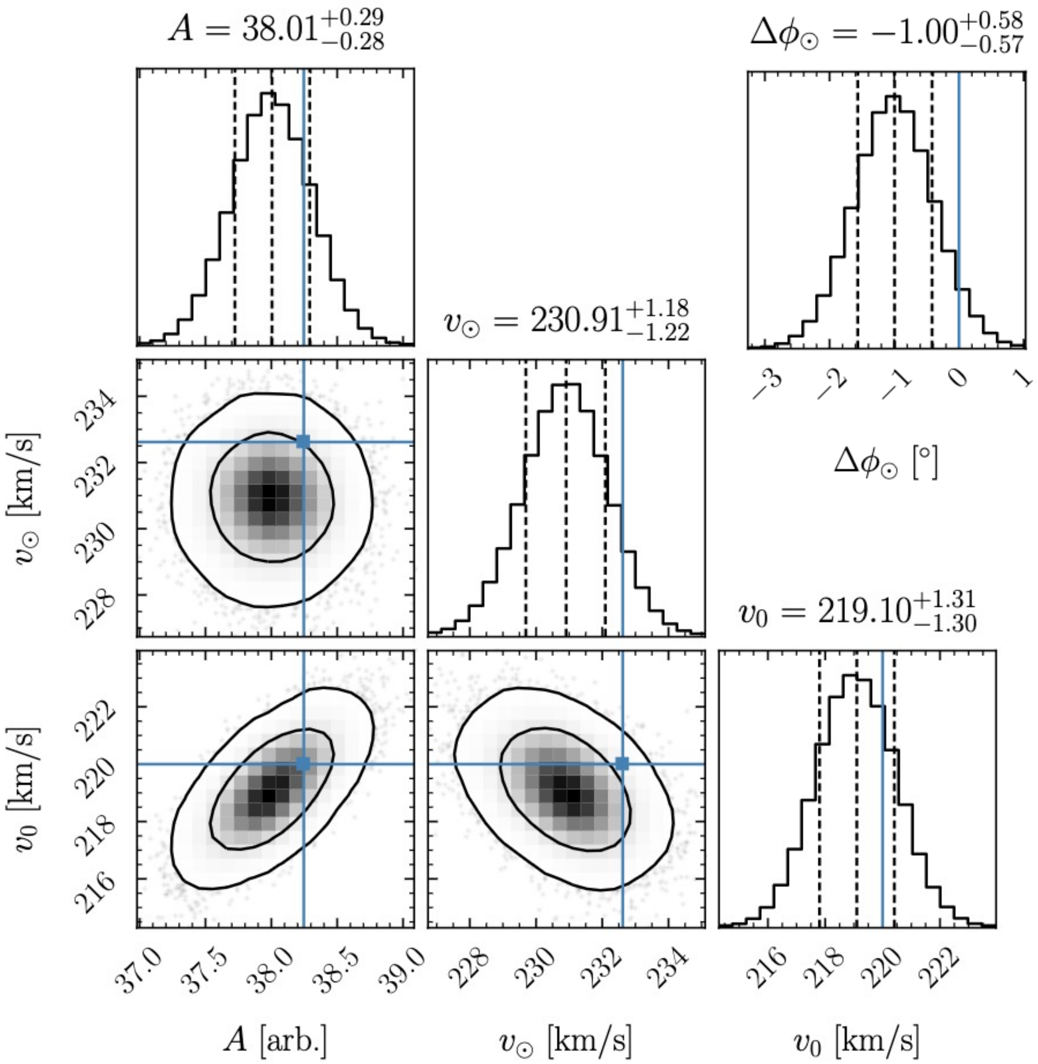
[J. Foster, *et al.* PRD103, 076018 (2021), arXiv:2009.14201]

"Modified Speed Distributions":



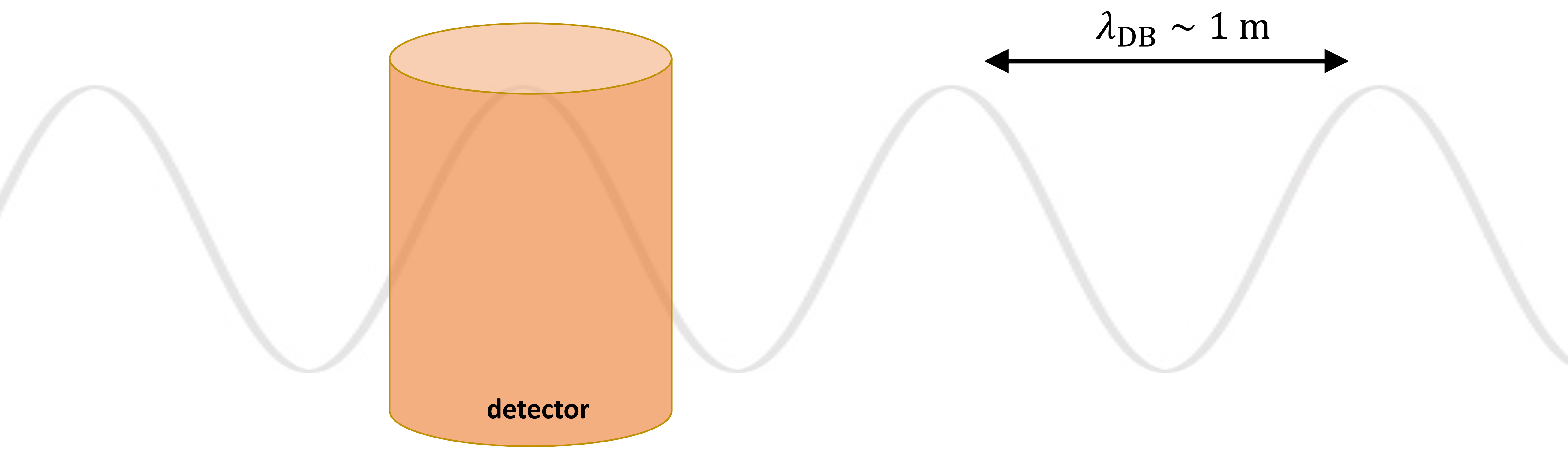
[J. Foster, *et al.* PRD103, 076018 (2021), arXiv:2009.14201]
Dark matter interferometry
Joshua W. Foster, Yonatan Kahn, Rachel Nguyen, Nicholas L. Rodd, and Benjamin R. Safdi
Phys. Rev. D 103, 076018 – Published 26 April 2021

Sensitivity:



Wave-like Dark Matter

$$\rho_a \sim 0.45\,\frac{\mathrm{GeV}}{\mathrm{cm}^3} \qquad \lambda_{\mathrm{DB}} \sim \frac{2\pi}{m_a v} \sim 1\,\mathrm{m}\left(\frac{1\mathrm{meV}}{m_a}\right) \quad \rightarrow \quad \frac{\#\mathrm{particles}}{\lambda_{\mathrm{DB}}^3} \sim 10^{30}\left(\frac{1\mu\mathrm{eV}}{m_a}\right)^4$$

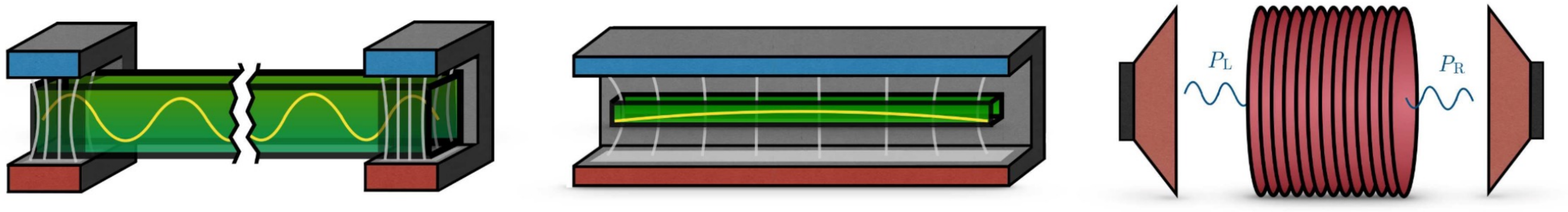


coherent detection w/ wavelength-dependent signal

Velocity-Dependent Form Factor

[SK, O'Hare, *et al.* JCAP11(2018)051, arXiv:1806.05927]

Partially Magnetized Cavity | **Long Thin Cavity** | **Dielectric Haloscope**



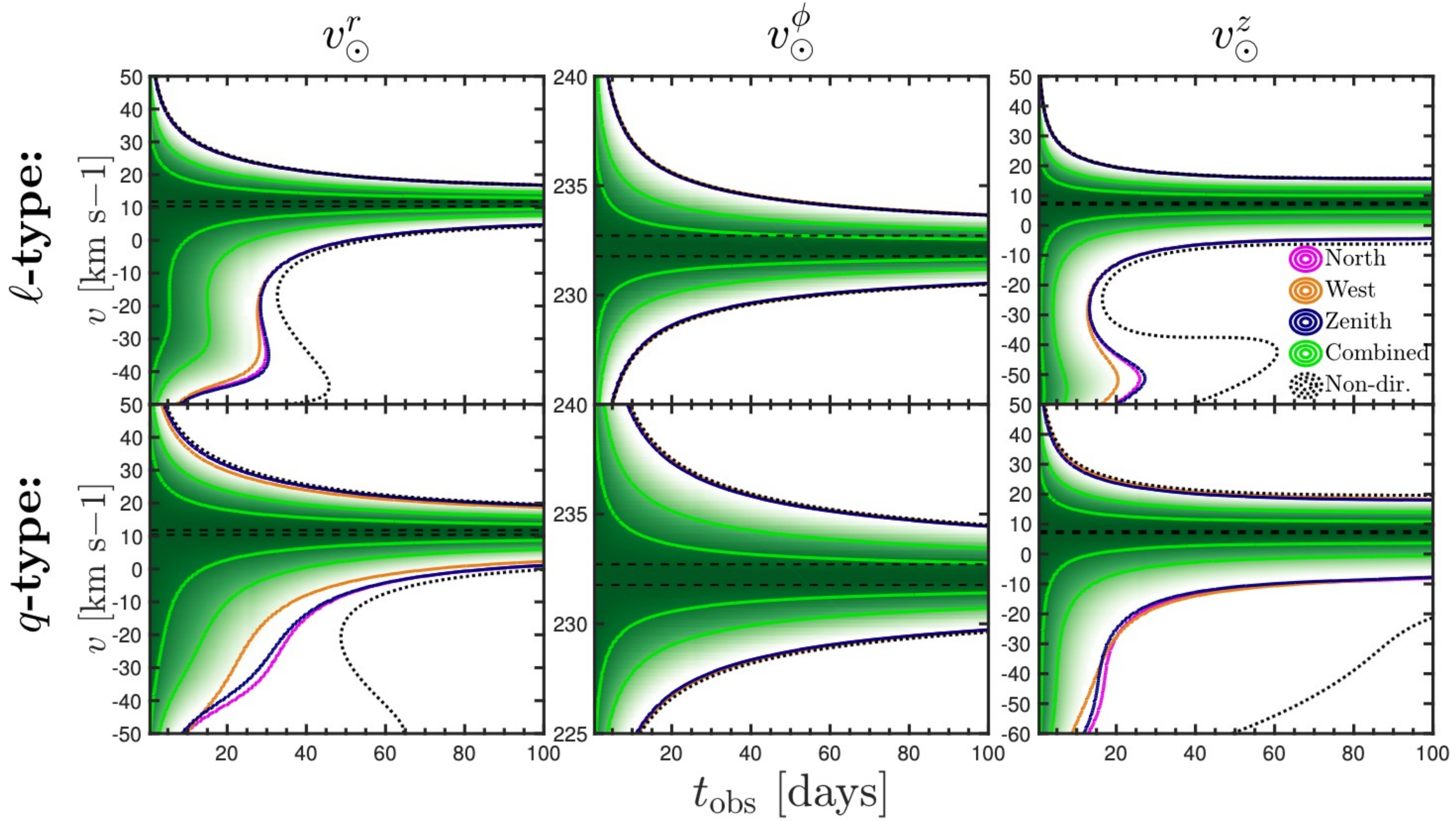
m_a	$10\,\mu\text{eV}$	$40\,\mu\text{eV}$	$100\,\mu\text{eV}$
λ_{dB}	$120\,\text{m}$	$30\,\text{m}$	$12\,\text{m}$

$$P_{\mathbf{p}} \propto \left| \int \mathrm{d}^3\mathbf{x}\, \mathbf{E}_{\mathbf{k}}(\mathbf{x}) \cdot \mathbf{B}_{\mathrm{e}} e^{i\mathbf{p}\cdot\mathbf{x}} \right|^2$$

→ modulate output power

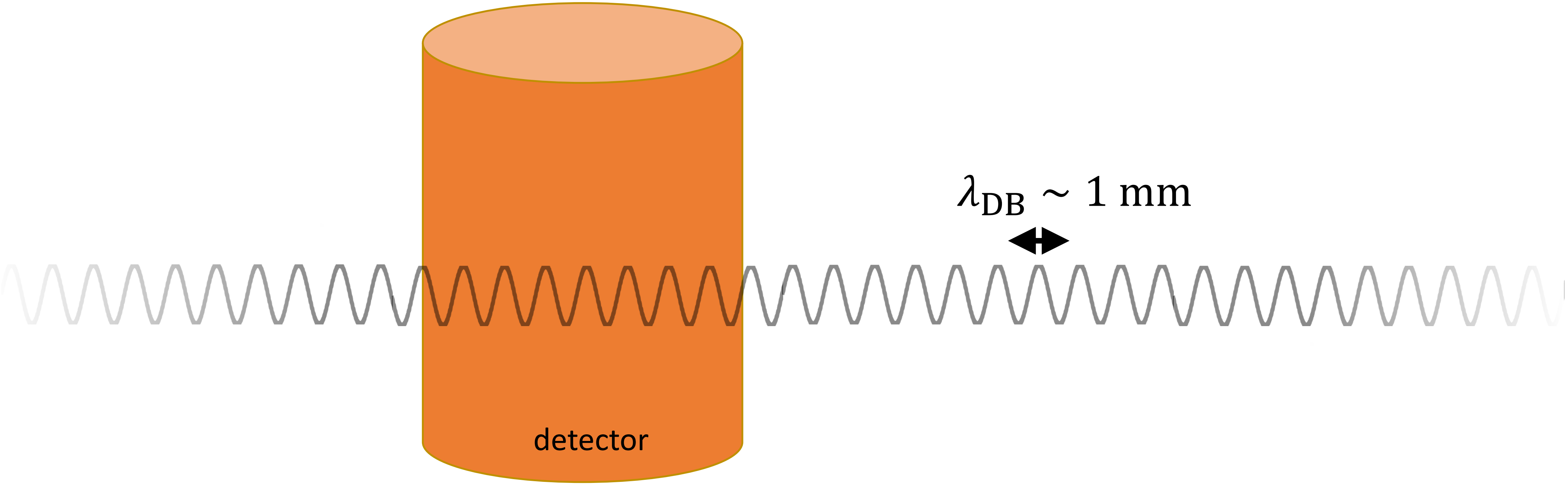
Sensitivity to Solar Velocity

[SK, O'Hare, *et al.* JCAP11(2018)051, arXiv:1806.05927]



Wave-like Dark Matter

$$\rho_a \sim 0.45\,\frac{\text{GeV}}{\text{cm}^3} \qquad \lambda_{\text{DB}} \sim \frac{2\pi}{m_a v} \sim 1\text{ mm}\left(\frac{1\text{eV}}{m_a}\right) \quad \rightarrow \quad \frac{\#\text{particles}}{\lambda_{\text{DB}}^3} \sim 10^6 \left(\frac{1\text{eV}}{m_a}\right)^4$$

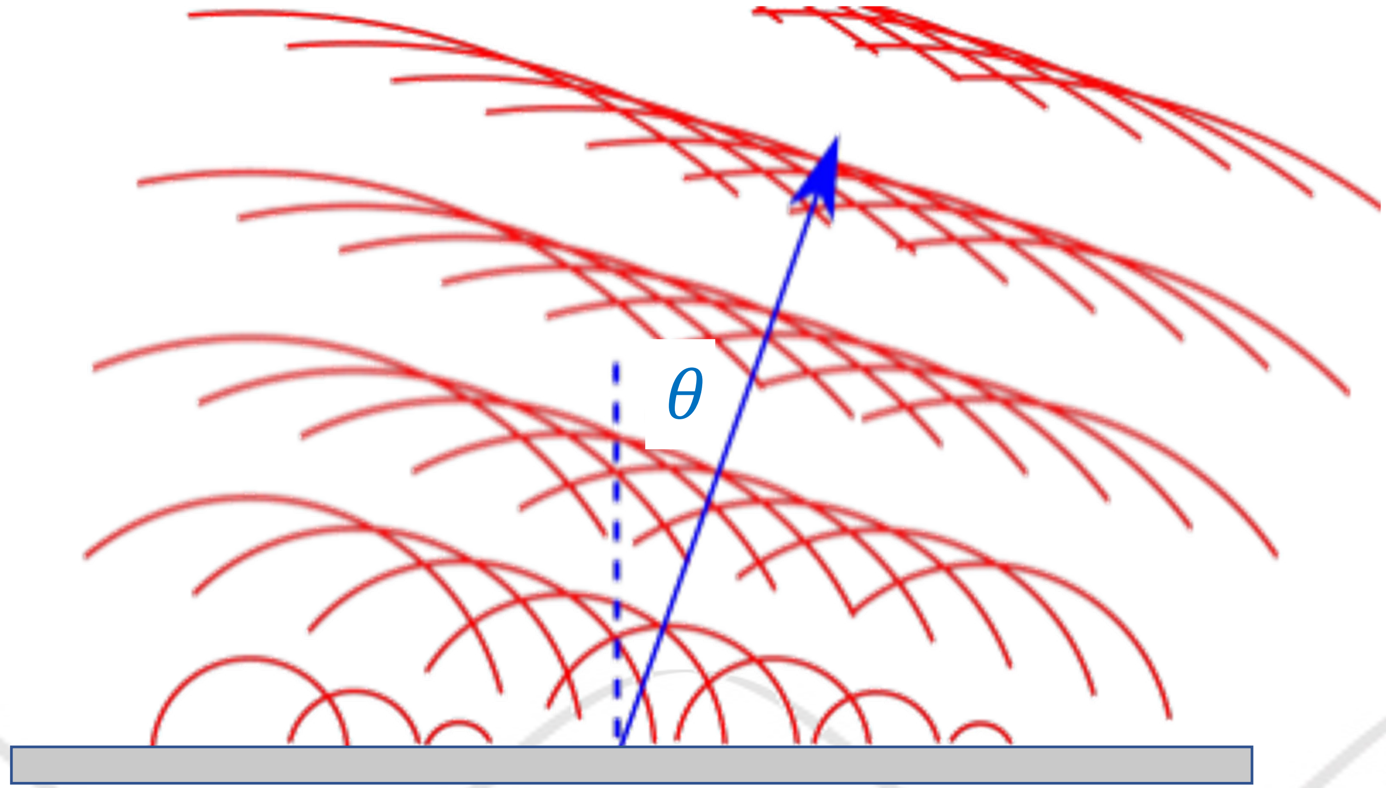


incoherent detection

Phase over Dish Surface

[https://en.wikipedia.org/wiki/Phased_array#/media/File:Phased_array_animation_with_arrow_10frames_371x400px_100ms.gif]

not to scale!



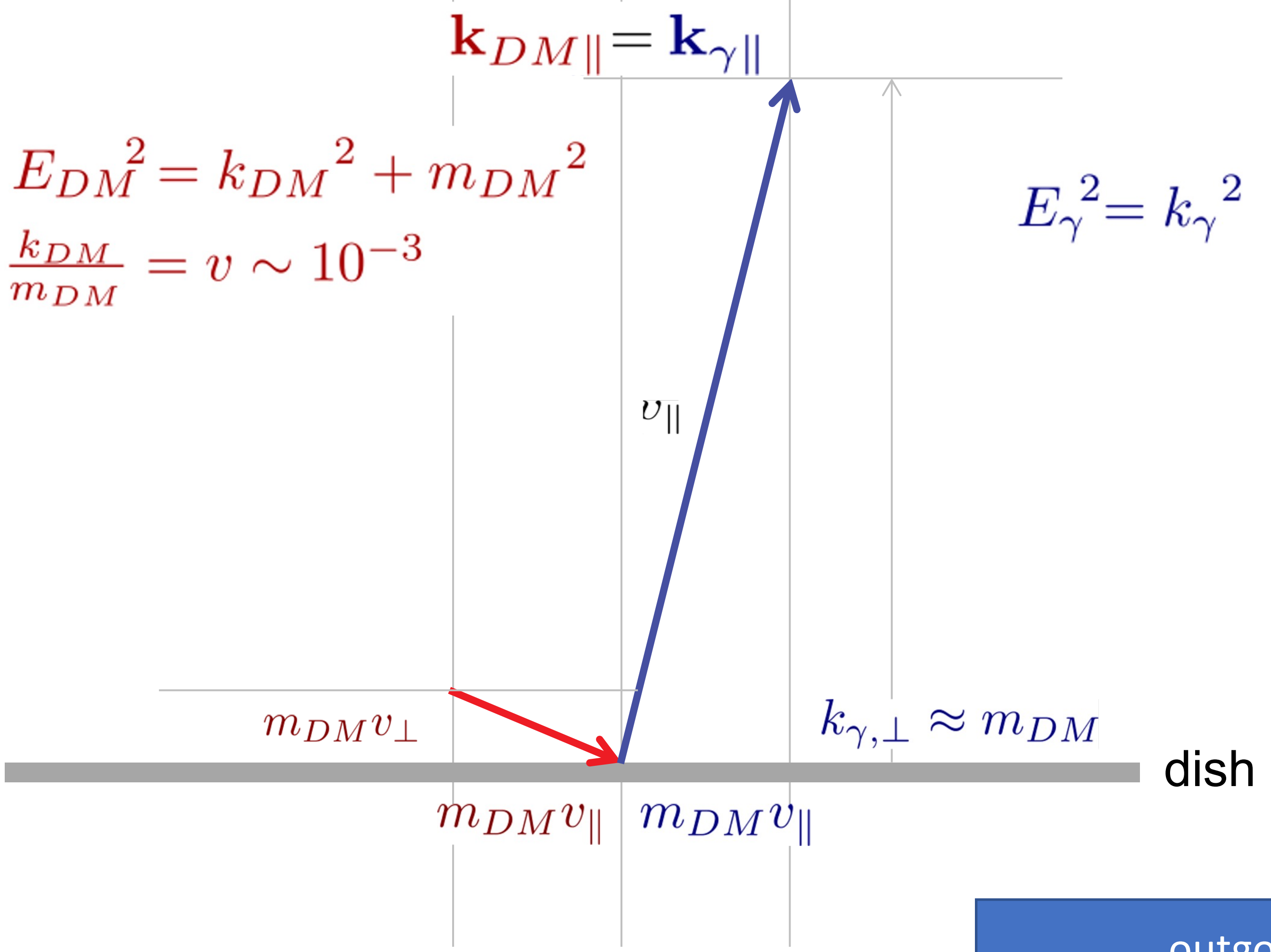
$$\lambda_{\mathrm{DB}} \sim \frac{2\pi}{m_a v}$$

→ signal excites a **spectrum of emission angles** over time

Particle Picture (ok if $\lambda_\gamma \ll D_{\mathrm{det}}$)

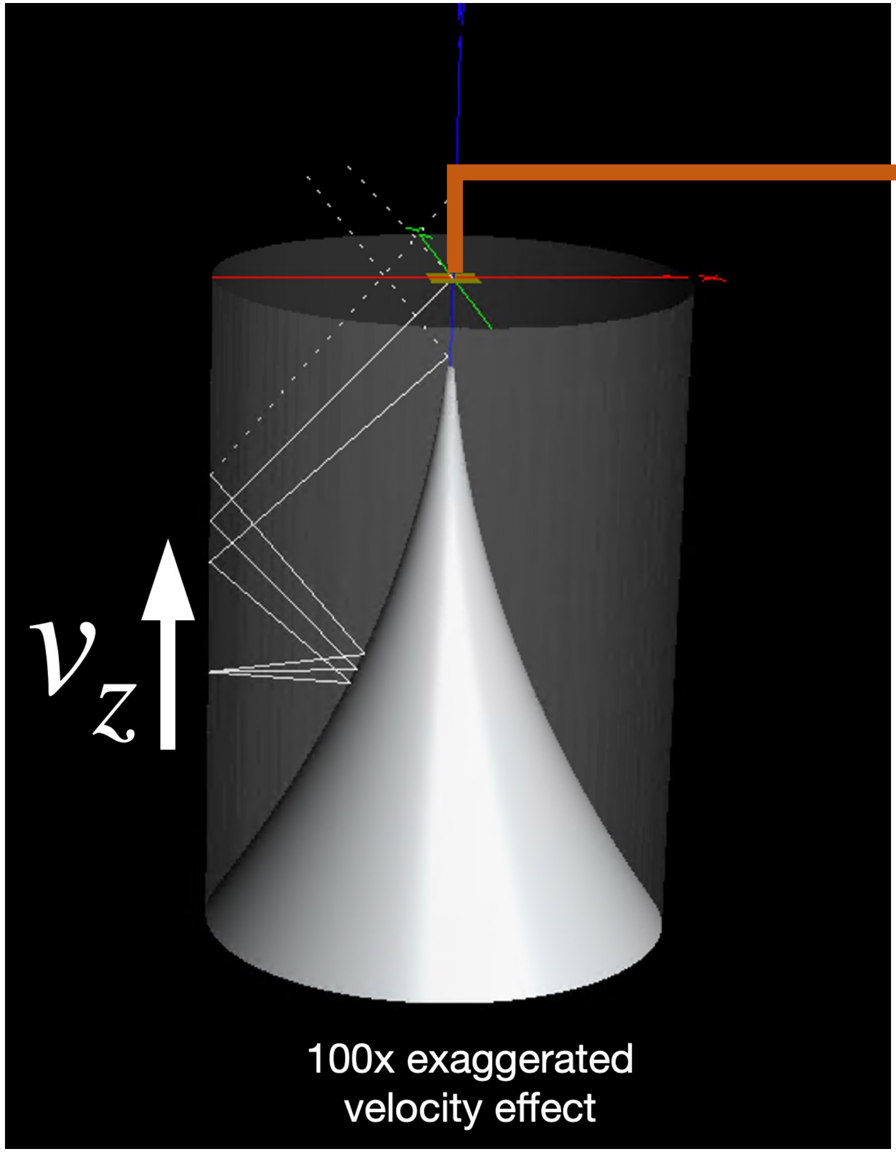
[Jaeckel, Redondo arXiv:1307.7181]
[Jaeckel, SK arXiv:1509.00371]

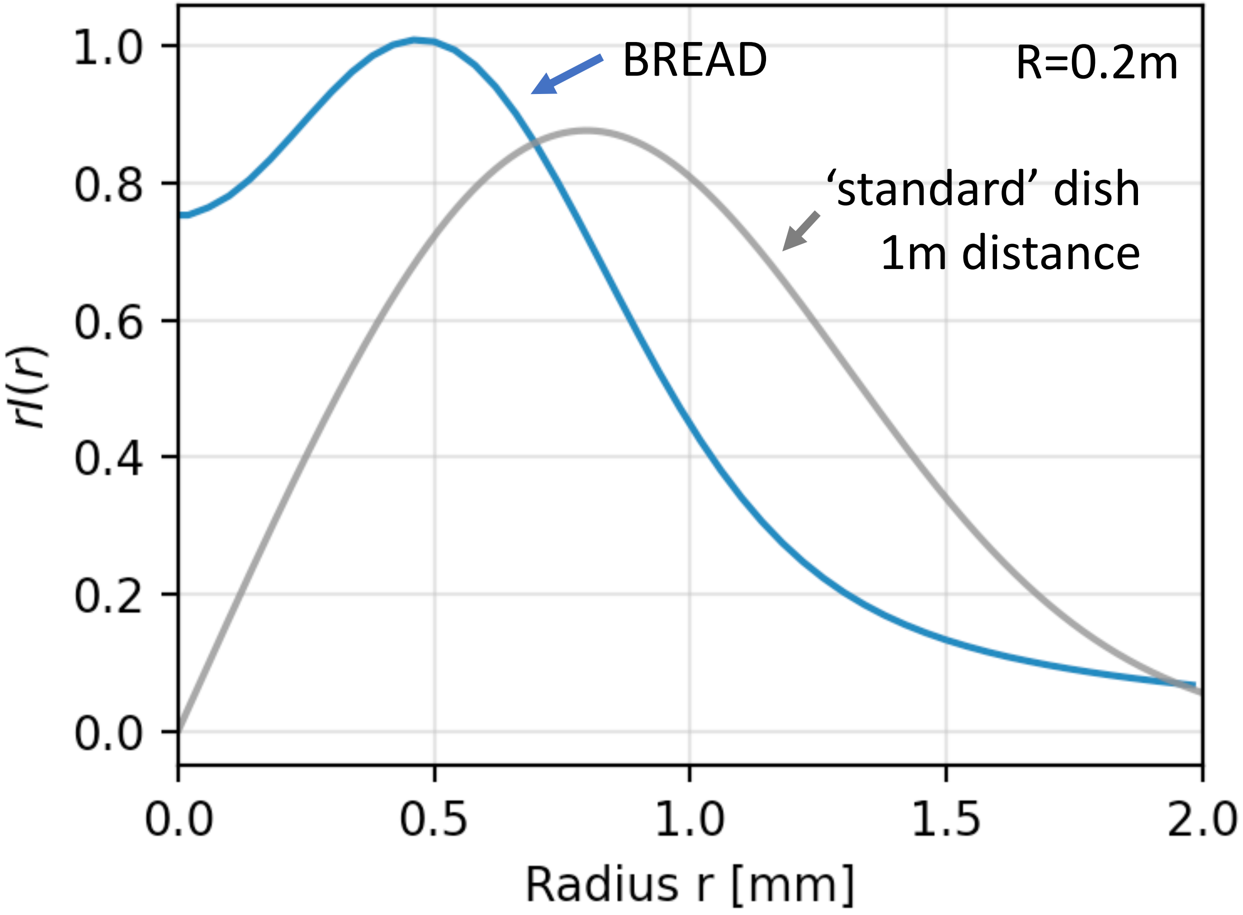
Incoming WISP: *Outgoing Photon:*



outgoing angle $\sim v \sim 10^{-3} c$

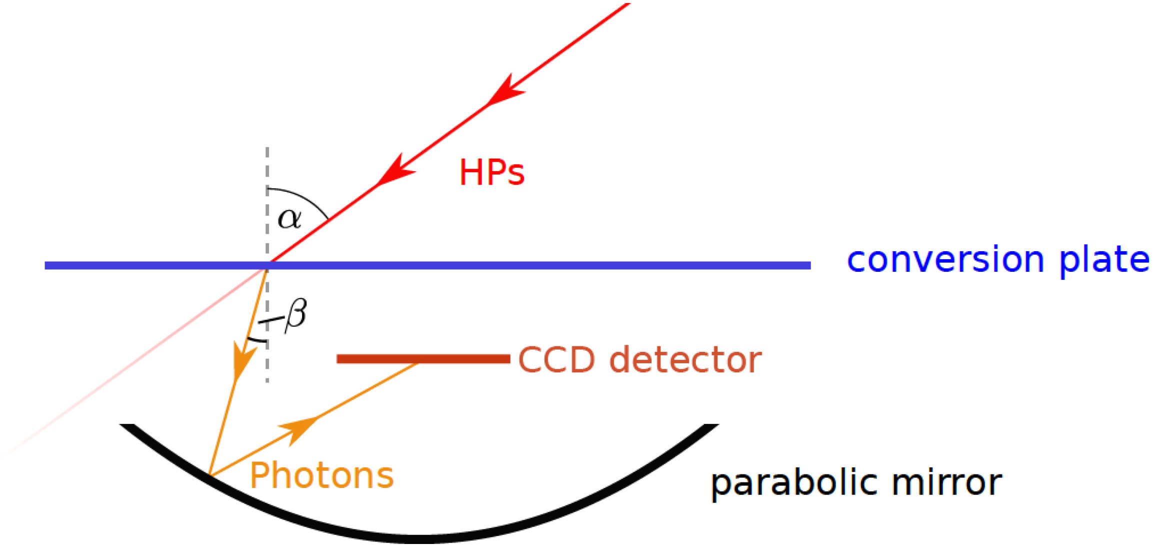
Example: BREAD

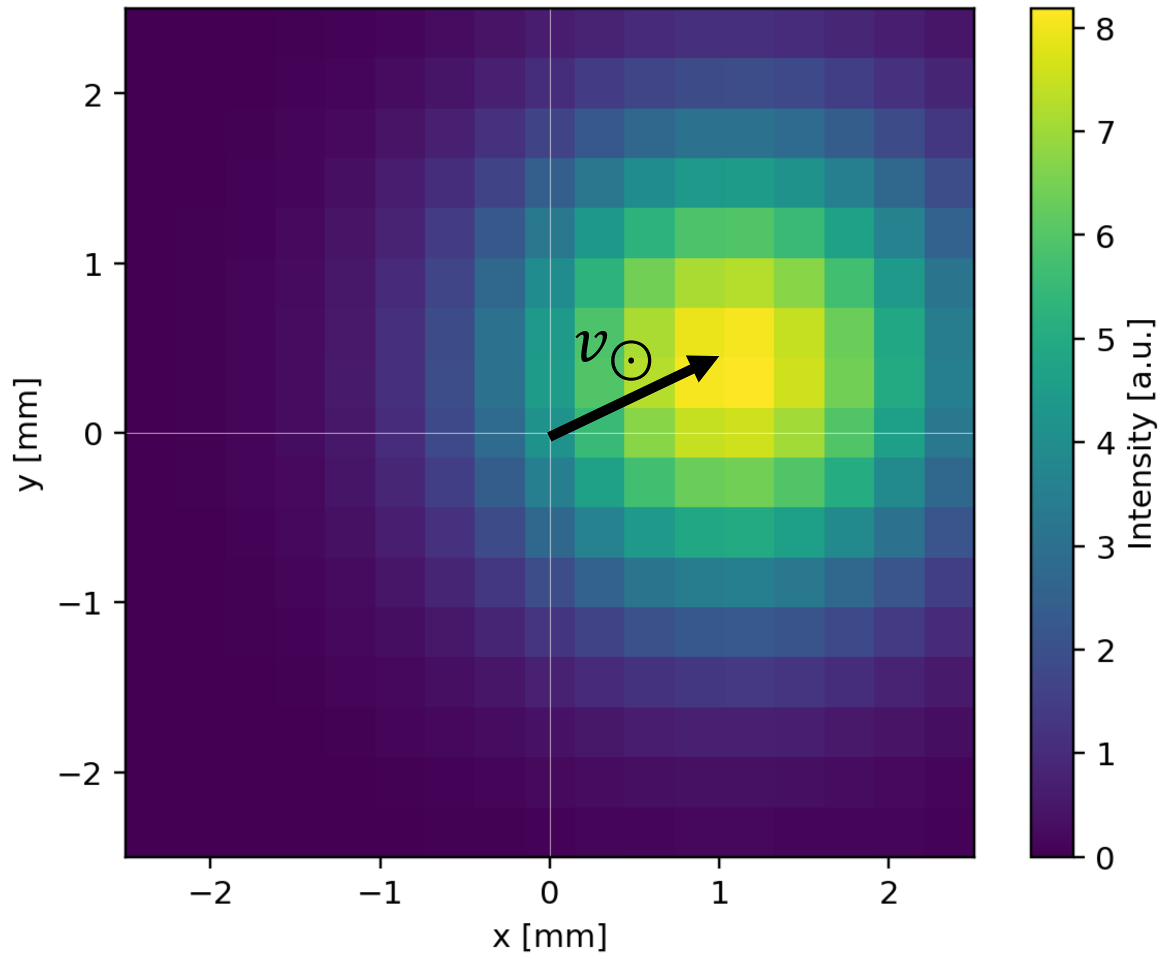




Axion Optical "Telescope"!

[Jaeckel, Redondo arXiv:1307.7181]
[Jaeckel, SK arXiv:1509.00371]





Discussion Points

- How to transform axion facilities quickly into axion telescopes?

- What is the sensitivity reach?
  Implications for Axion Models?
  Other astrophysics & cosmology?
  - Velocity Distribution Tail
  - Substructure / Streams
  - …
  - What is missing?

- What if axions are discovered but not dark matter, could haloscope (facilities) still be useful?

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