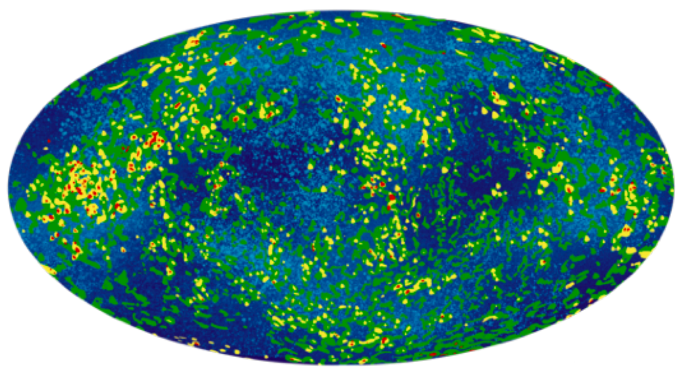
Searches of Low-Mass Dark Matter

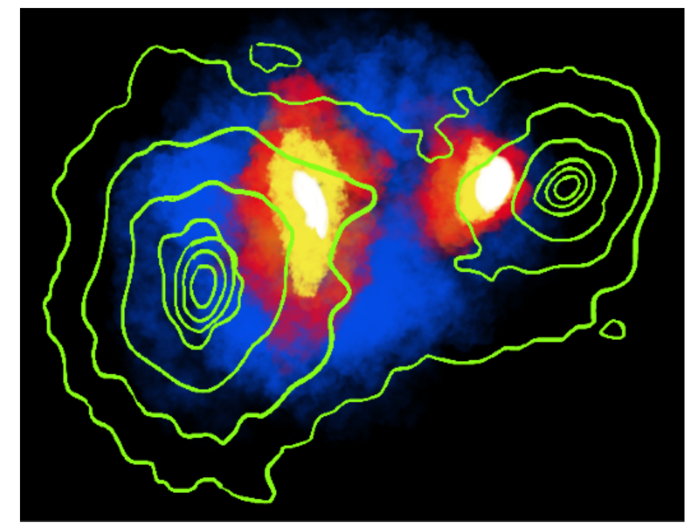
Clara Murgui (CERN)

PASCOS — July 22nd 2025 — Durham

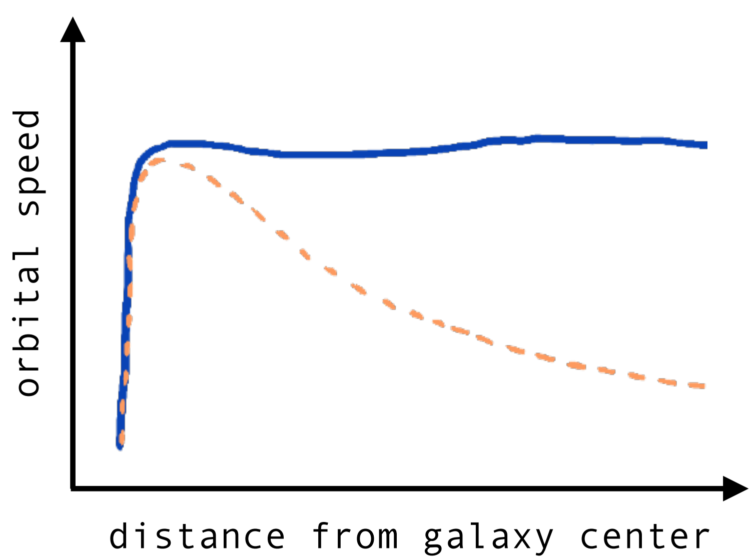
Echoes of the Unseen



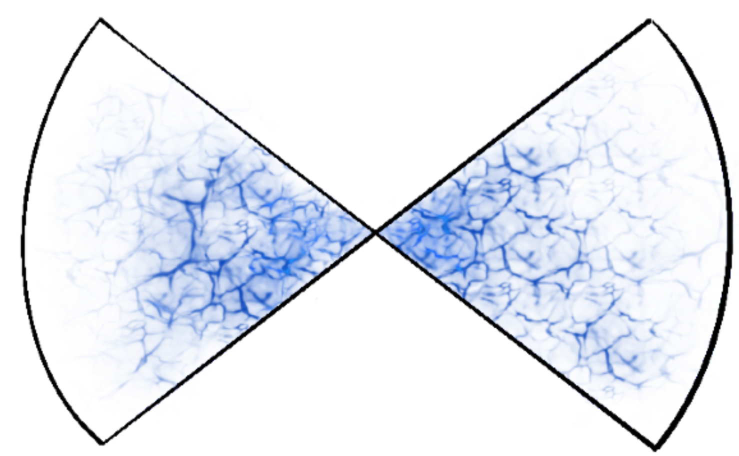
Observed DM density
@ CMB



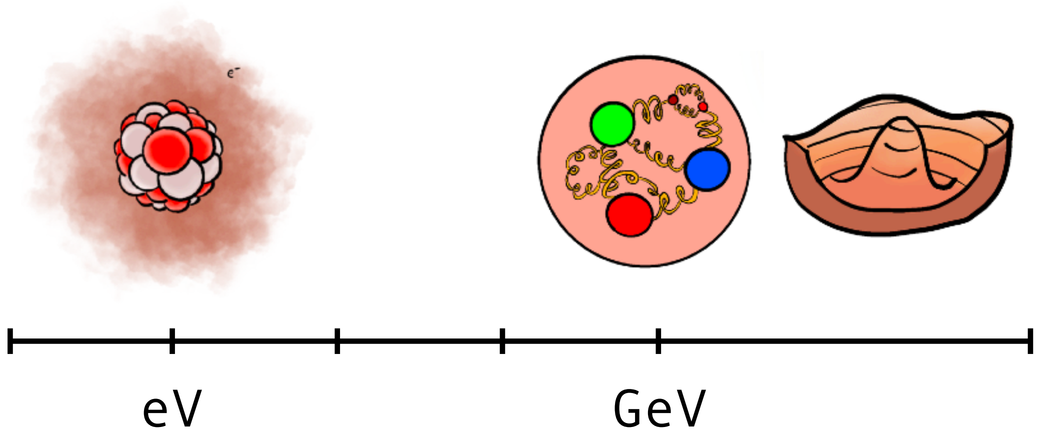
Gravitational lensing
(e.g. Bullet cluster)

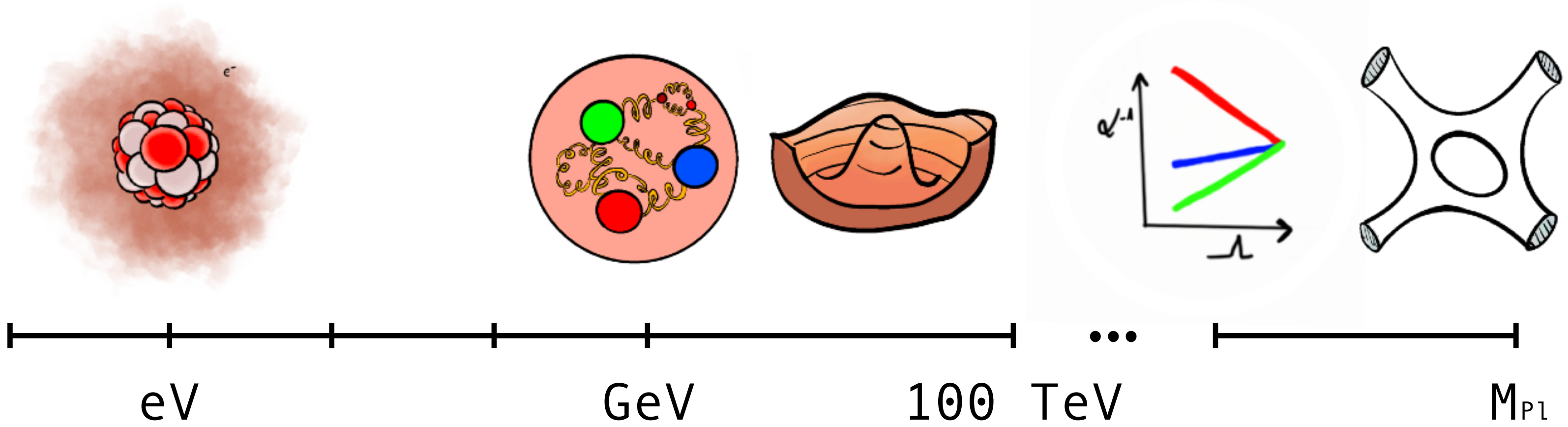


Galaxy rotation curves

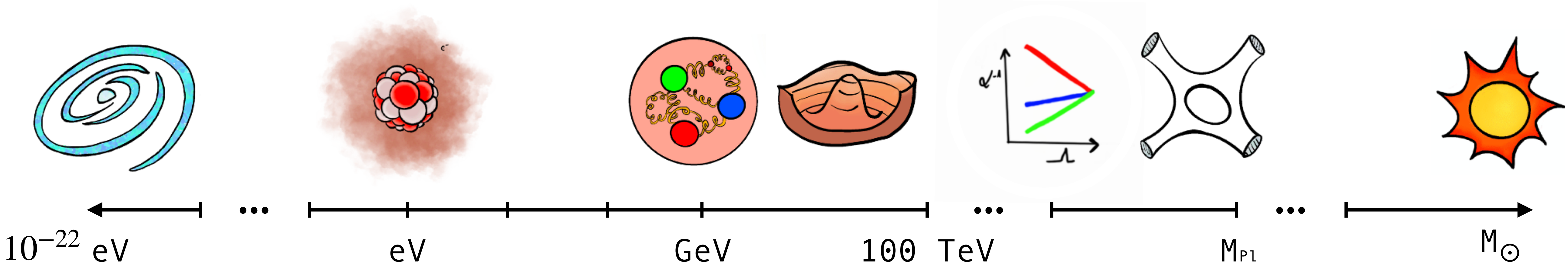


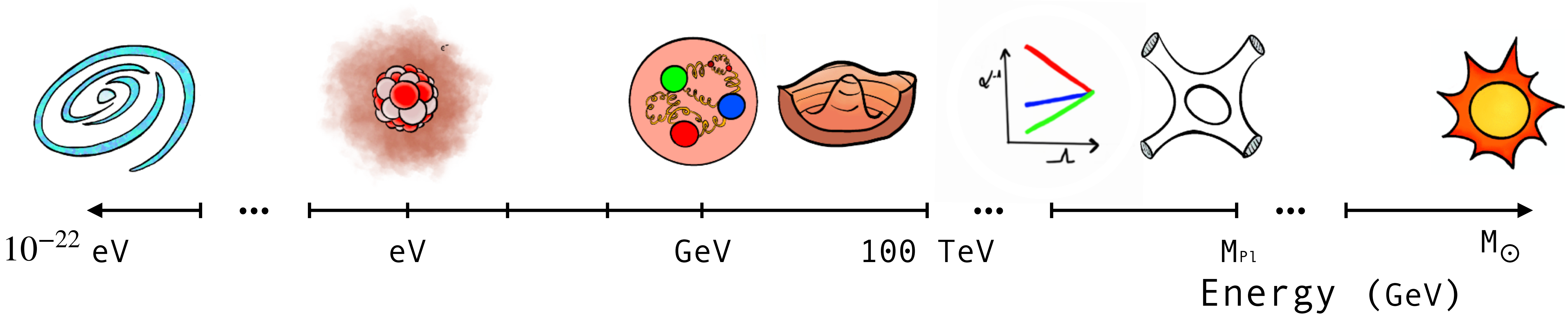
LSS formation


eV
GeV



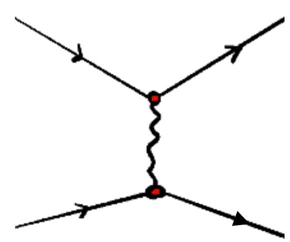
eV
GeV
100 TeV
M_{Pl}


10^{-22} eV
eV
GeV
100 TeV
M_{Pl}
$M_{\odot}$

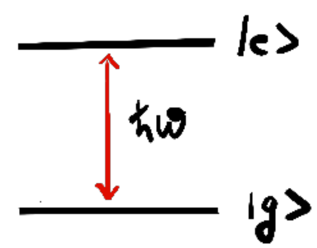


Spans over many branches…
…all over the world

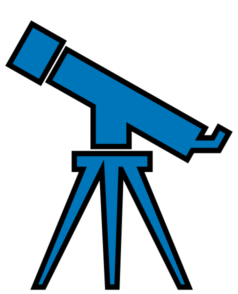
nuclear physics



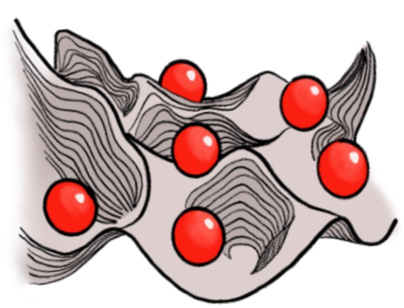
particle physics



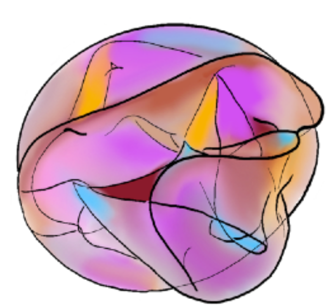
quantum optics, AMO



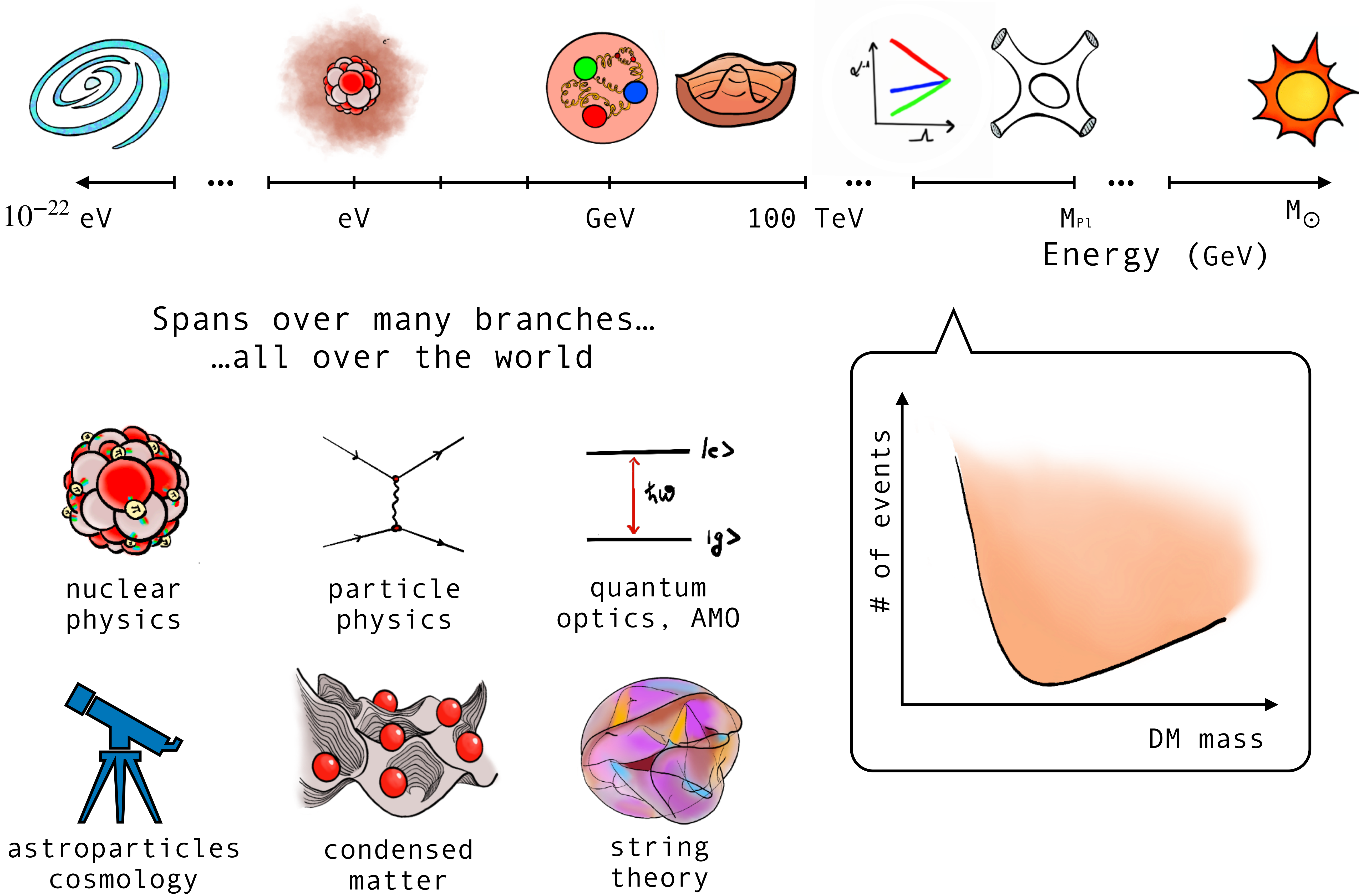
astroparticles cosmology



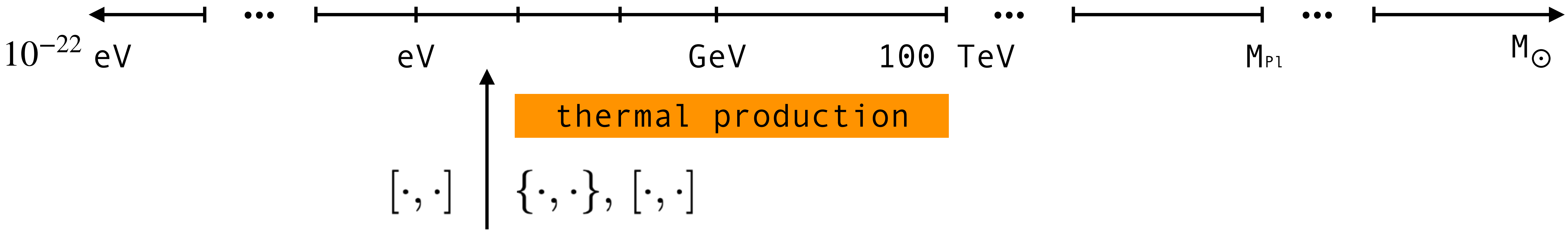
condensed matter



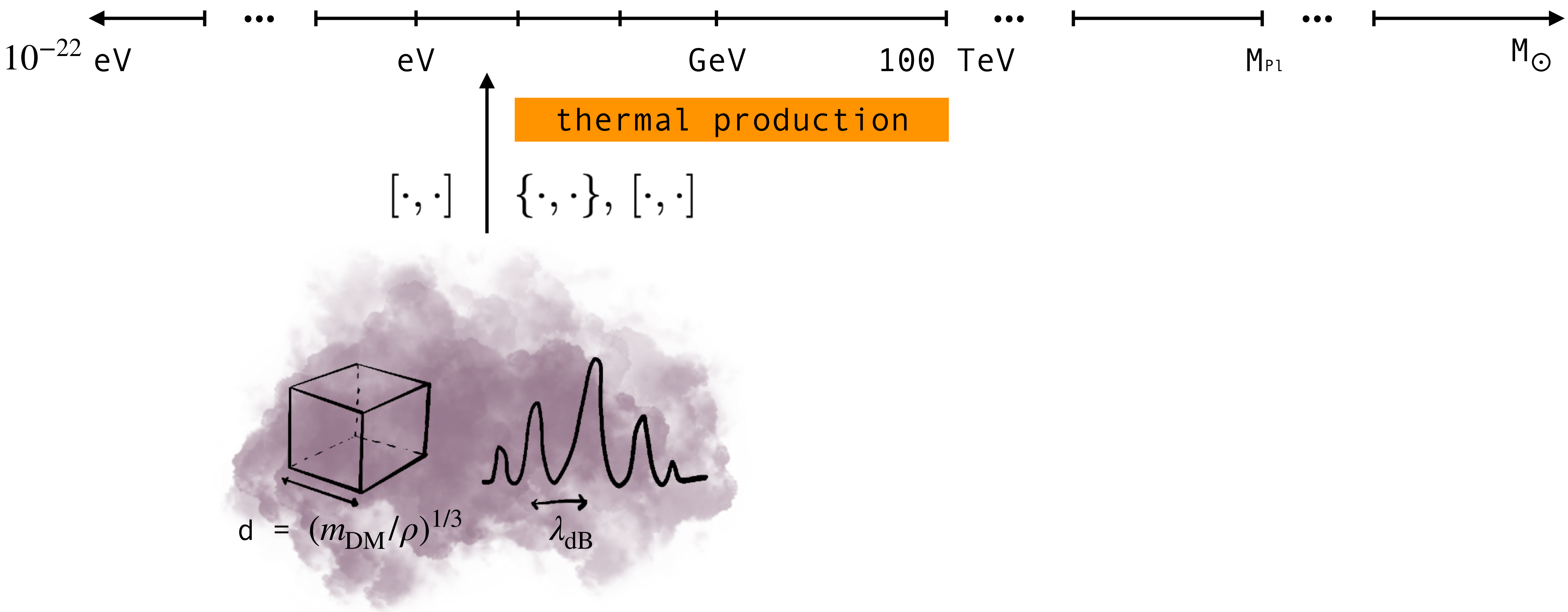
string theory



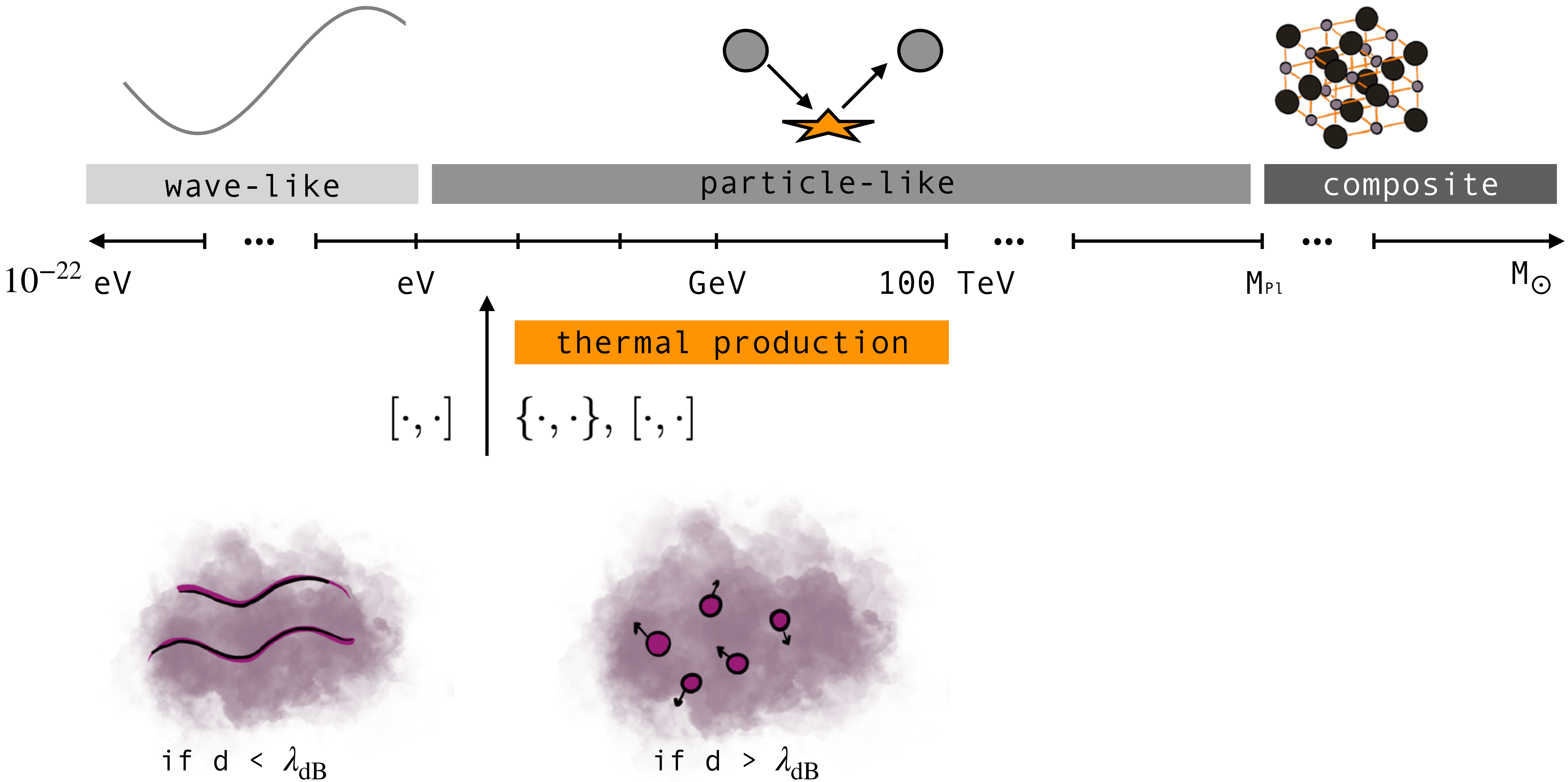
10^{-22} eV
eV
GeV
100 TeV
M_{Pl}
$M_\odot$
Energy (GeV)
Spans over many branches…
…all over the world
nuclear physics
particle physics
quantum optics, AMO
astroparticles cosmology
condensed matter
string theory
# of events
DM mass



10^{-22} eV
eV
GeV
100 TeV
M_{Pl}
$M_{\odot}$
thermal production
$[\cdot,\cdot]$
$\{\cdot,\cdot\}$, $[\cdot,\cdot]$



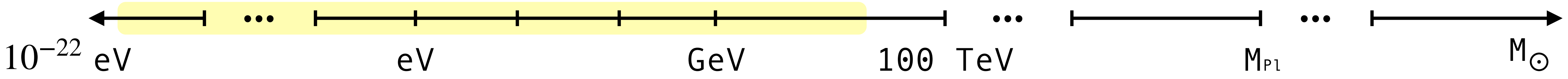
10^{-22} eV
eV
GeV
100 TeV
M_{Pl}
$M_\odot$
thermal production
$[\cdot,\cdot]$
$\{\cdot,\cdot\}$, $[\cdot,\cdot]$
d = $(m_{DM}/\rho)^{1/3}$
λ_{dB}



wave-like
particle-like
composite
10^{-22} eV
eV
GeV
100 TeV
M_{Pl}
$M_\odot$
thermal production
$[\cdot,\cdot]$
$\{\cdot,\cdot\}, [\cdot,\cdot]$
if d < λ_{dB}
if d > λ_{dB}

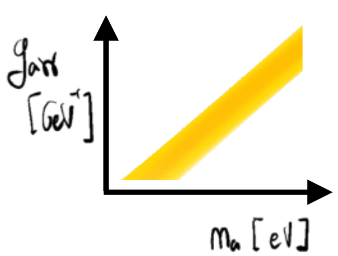
Where do we expect it?

Having a goal

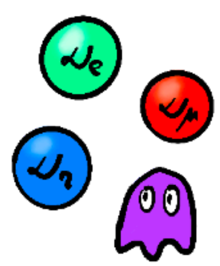


Where do we expect it?

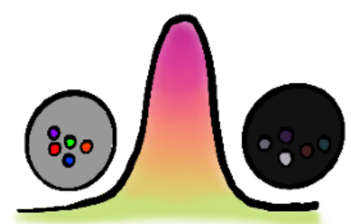
Having a goal



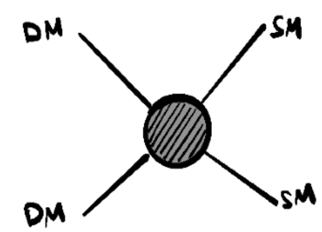
axions



sterile Neutrinos

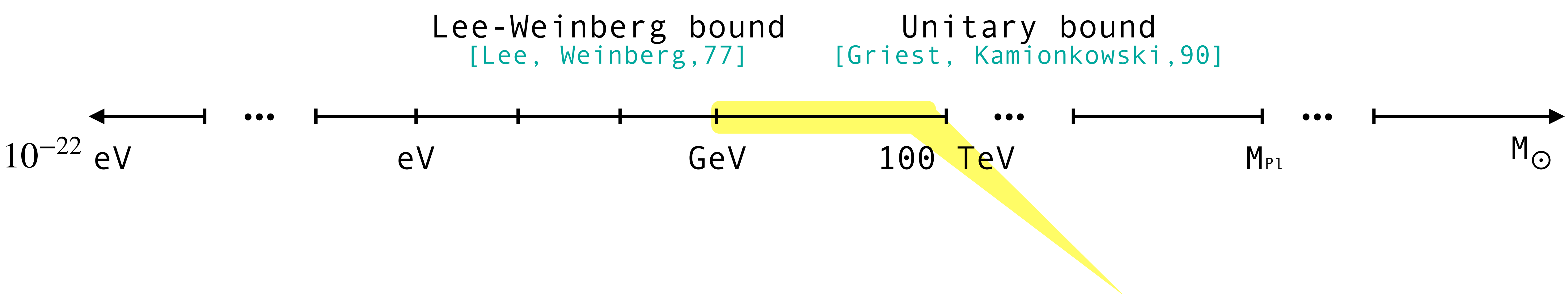


hidden sector

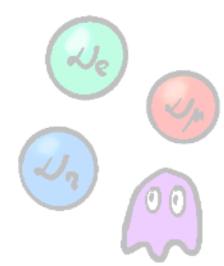


WIMPs

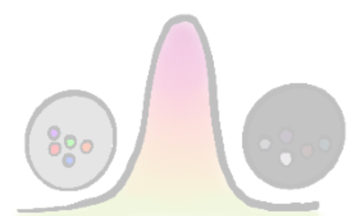
Where do we expect it?



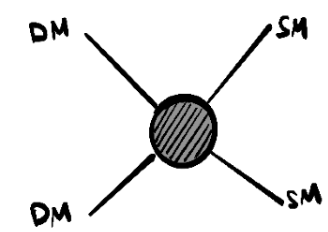
axions



sterile Neutrinos

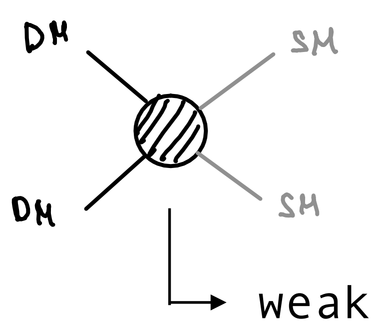


hidden sector



WIMPs

WIMP miracle



$$\langle \sigma v \rangle \sim \frac{G_F^2}{8\pi} m_{\rm DM}^2 \frac{c}{3}$$

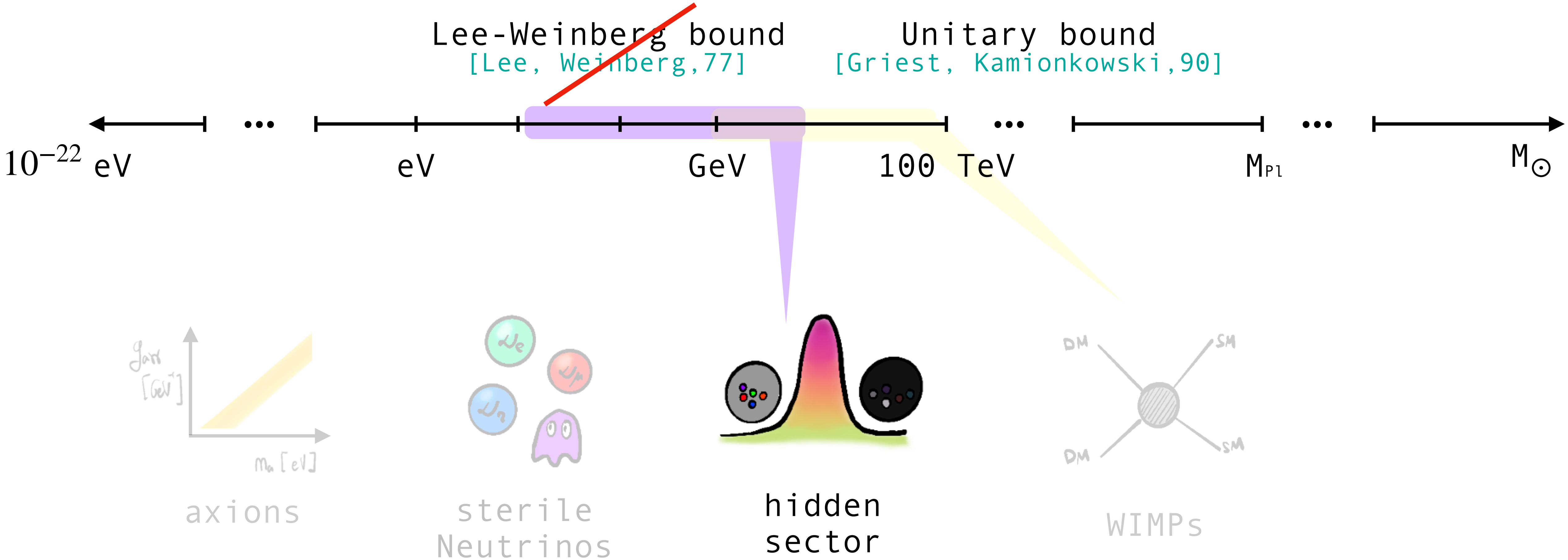
if $m_{\rm DM} \sim \Lambda_{\rm EW}$

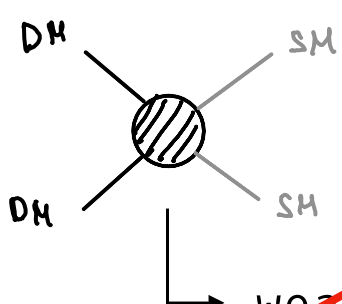
$$\Omega_{\rm DM} \sim 0.1 \times \left(\frac{3 \times 10^{-26}\ {\rm cm}^3/{\rm s}}{\langle \sigma v \rangle} \right)$$

e.g. neutralino (SUSY) [Goldberg.'83] [Ellis et al.,'84]

e.g. minimal DM [Cirelli et al.'06]

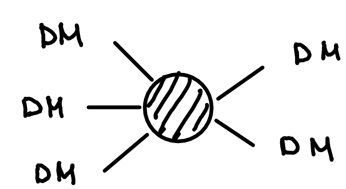
Where do we expect it?





~~weak~~ $\mathcal{G}_{\rm SM} \otimes {\rm U}(1)_X$

e.g. SIMP miracle
[Hochberg, et al. 14]



e.g. asymmetric DM
[Kaplan, Luty, Zurek, 09]

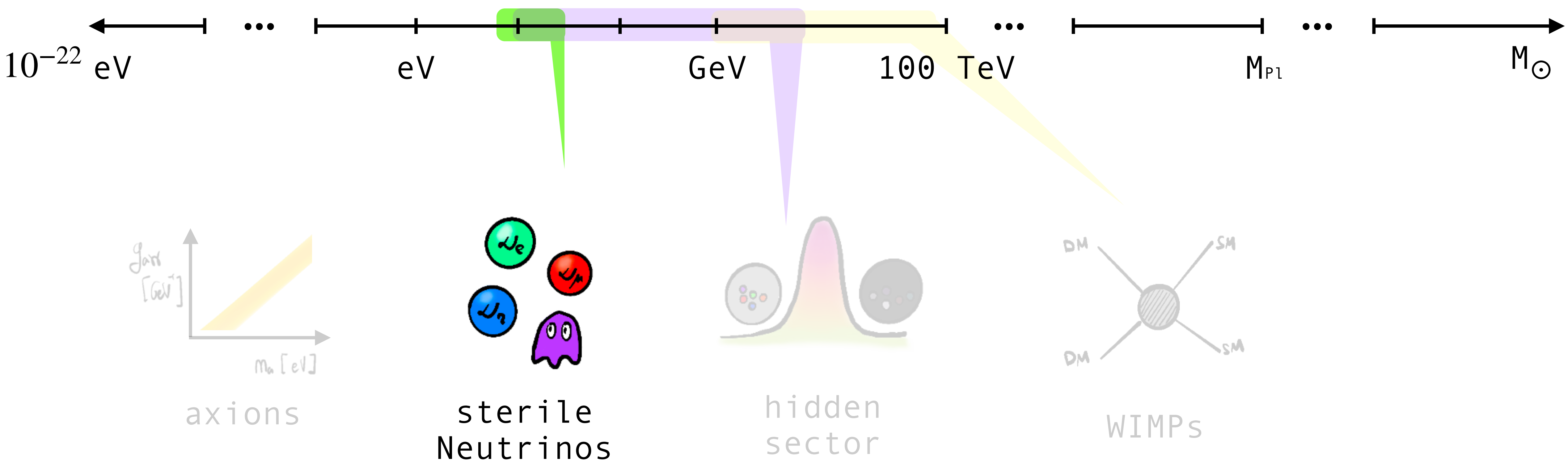
$$\frac{\Omega_{\rm DM}}{\Omega_{\rm B}} = \frac{m_{\rm DM} Y_{\rm DM}}{m_p Y_B} \sim 5$$

e.g. accidental symmetries

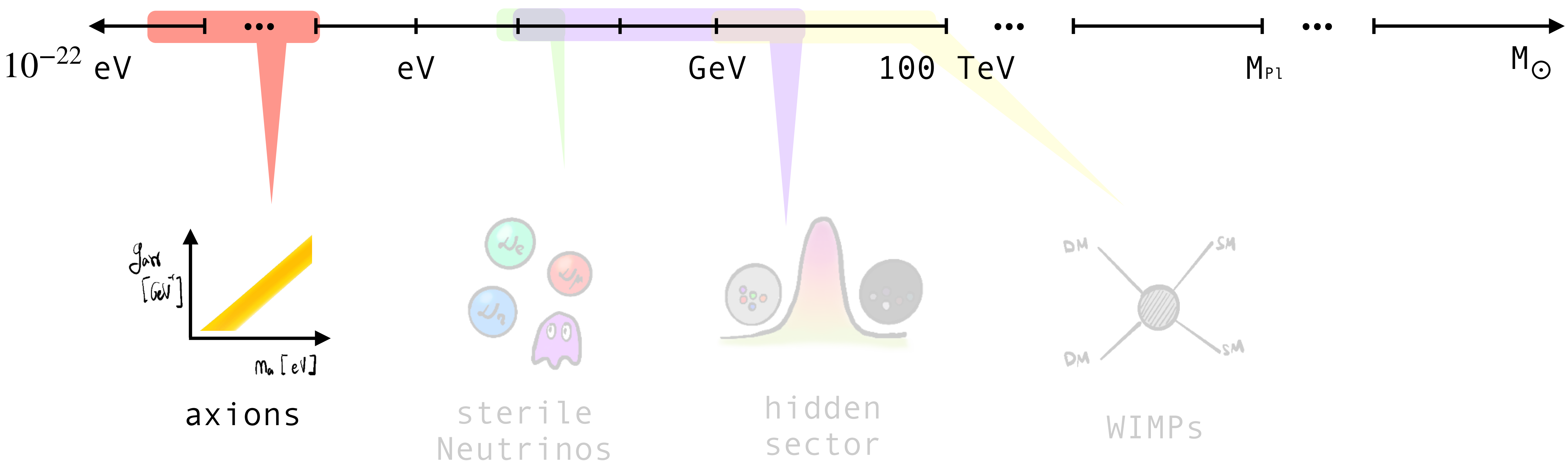
$$\mathcal{L} \supset \mathcal{L}_{\rm SM} + \frac{1}{\Lambda} \ell_L \ell_L HH + \frac{1}{\Lambda} Q_L Q_L Q_L \ell_L + \cdots \quad {\rm U}(1)_B, {\rm U}(1)_L$$

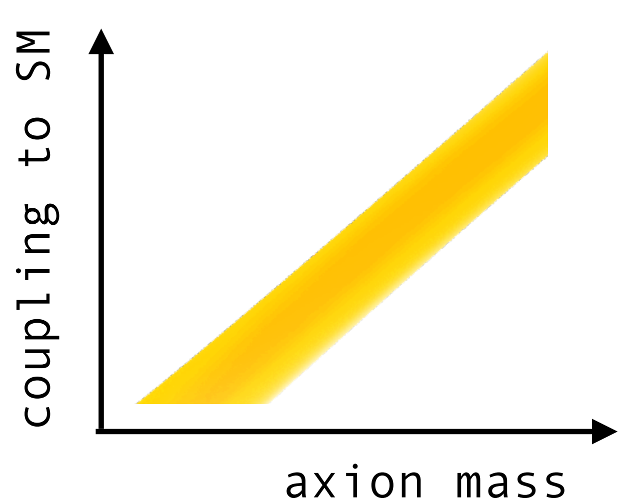
[Fileviez, Wise, 10]

Where do we expect it?

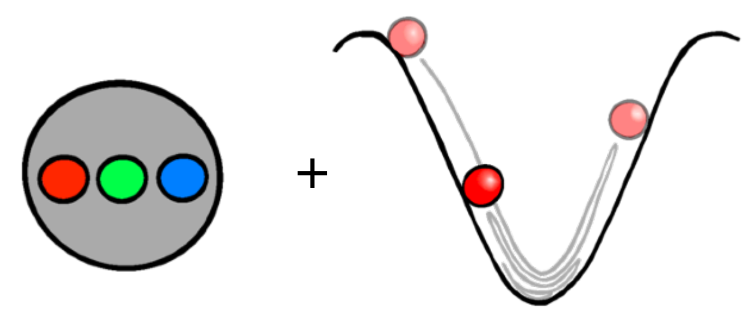


Where do we expect it?



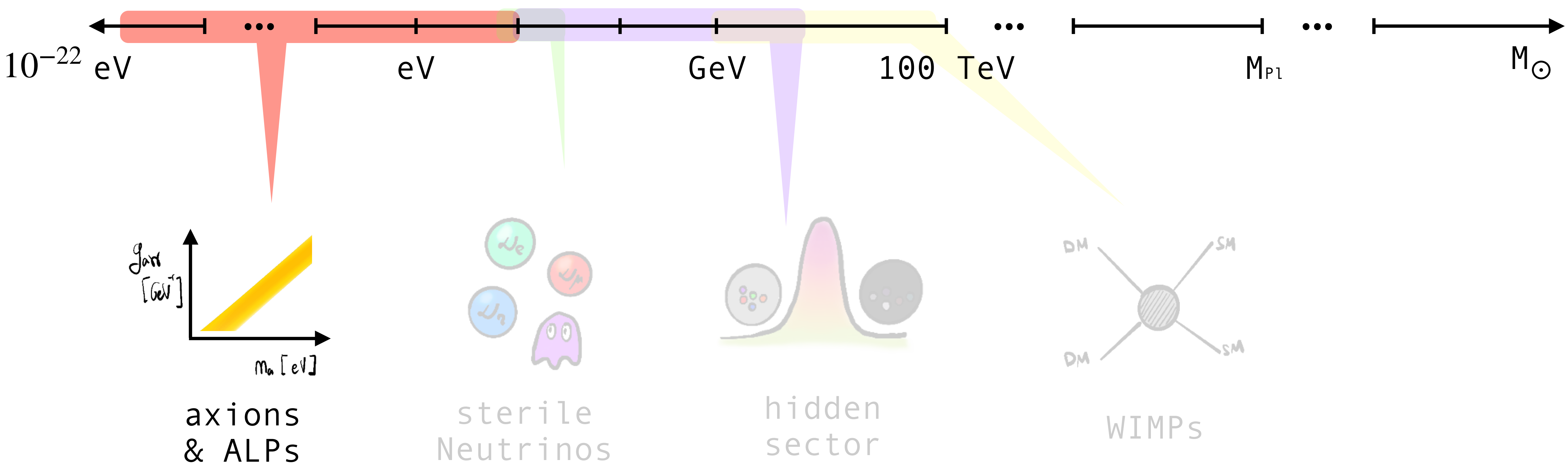


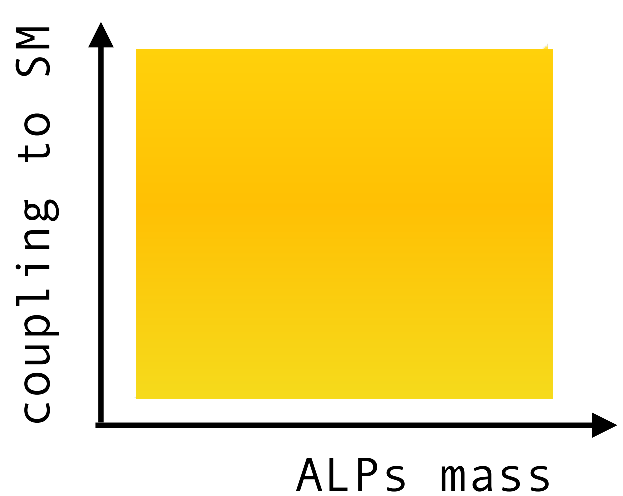
$$g_{a\mathrm{SM}} \propto \frac{1}{f_a}$$



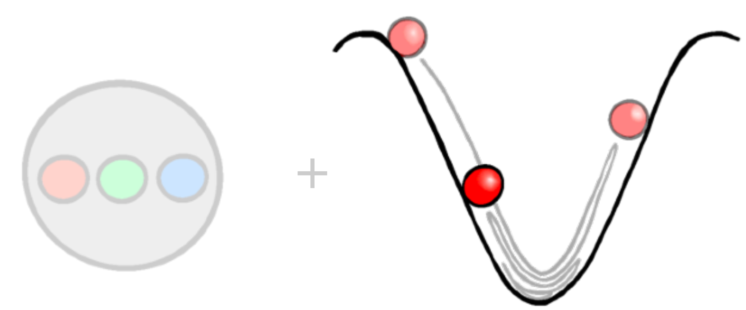
$$V(a) = \Lambda_{\mathrm{QCD}}^4 \left[1 - \cos\left(\frac{a}{f_a}\right)\right] \;\longrightarrow\; m_a \sim \frac{\Lambda_{\mathrm{QCD}}^2}{f_a}$$

Where do we expect it?



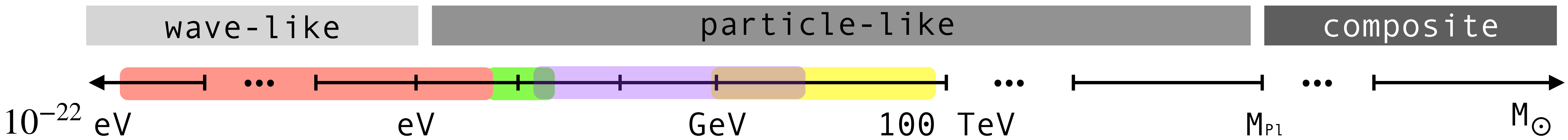


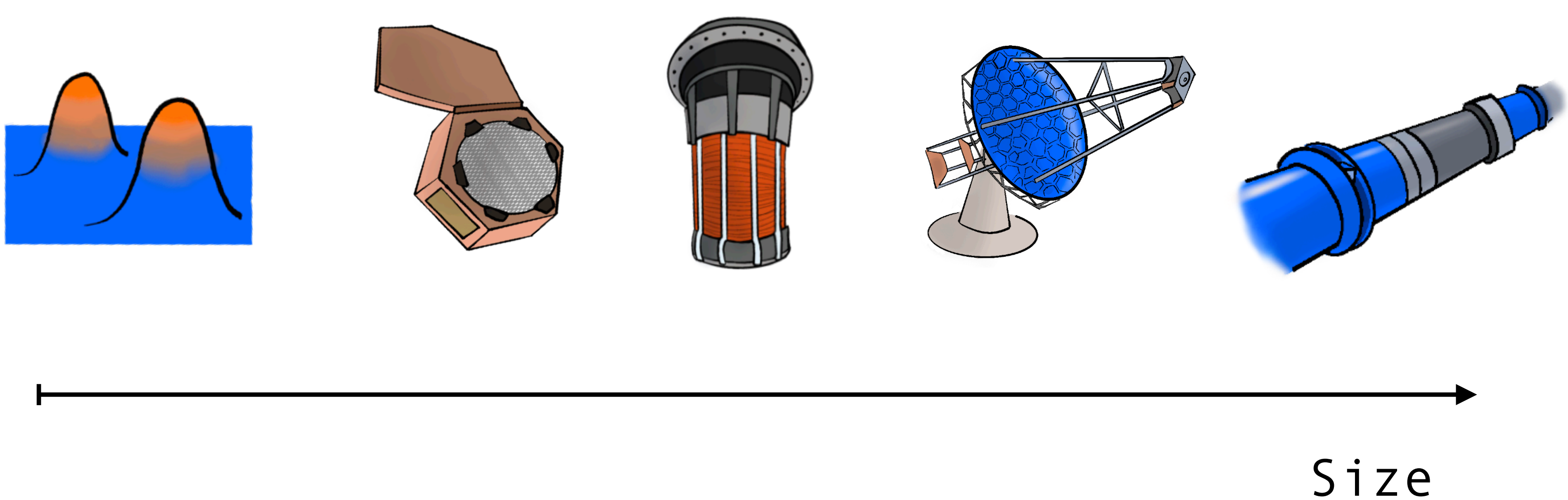
$$g_{a\mathrm{SM}} \propto \frac{1}{f_a}$$



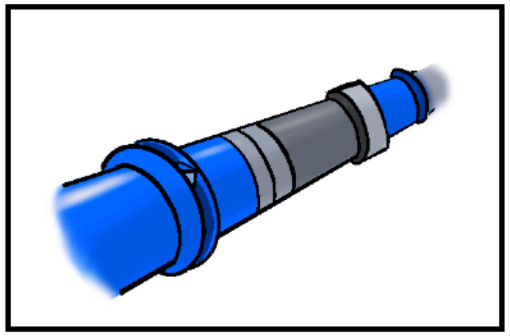
$$V(a) = \Lambda_{\mathrm{QCD}}^4 \left[1 - \cos\left(\frac{a}{f_a}\right)\right] \longrightarrow m_a \sim \frac{\Lambda_{\mathrm{QCD}}^2}{f_a}$$

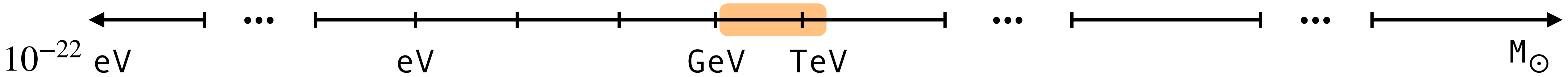
Lamposts


wave-like
particle-like
composite
10^{-22} eV
eV
GeV
100 TeV
M_{Pl}
$M_{\odot}$


Size

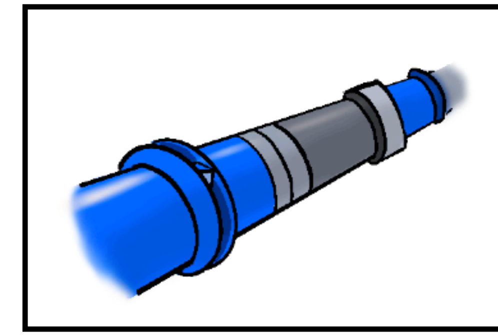
Collider searches

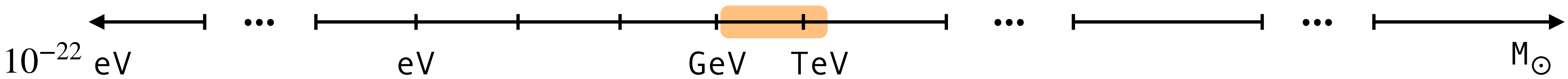




Collider searches

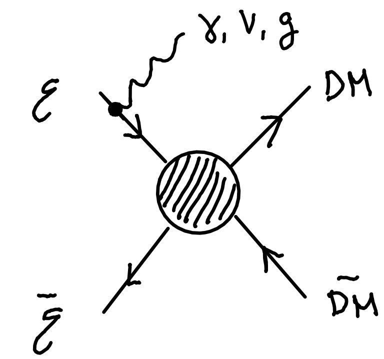
EFTs





Mono-object + missing energy

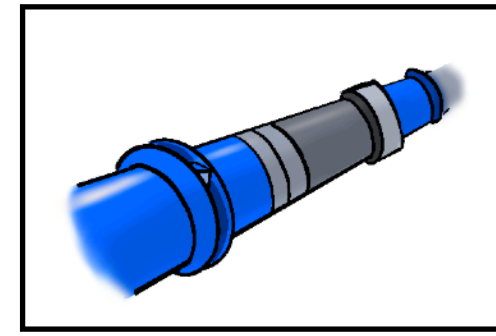
pp → DM $\overline{\text{DM}}$ + something (jet, Z, Higgs…)

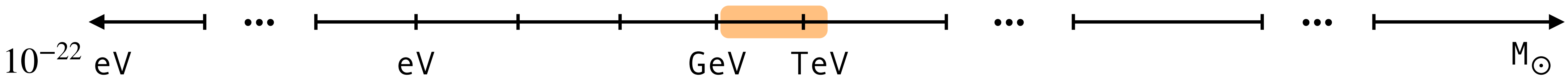


$\Lambda_{NP} \gg s$

Collider searches

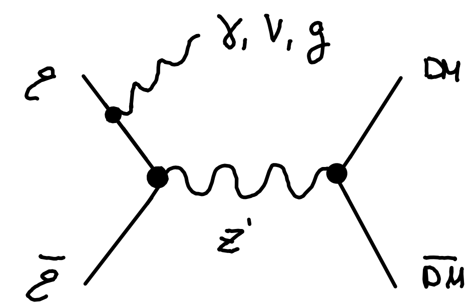
Theories





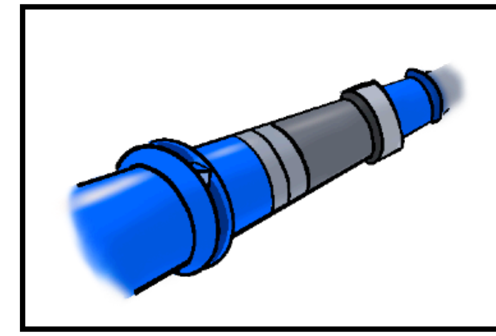
Mono-object + missing energy

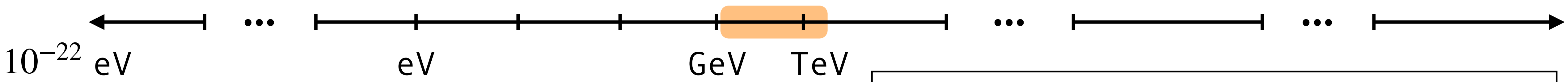
pp → Mediator* → DM $\overline{\text{DM}}$ + something



Collider searches

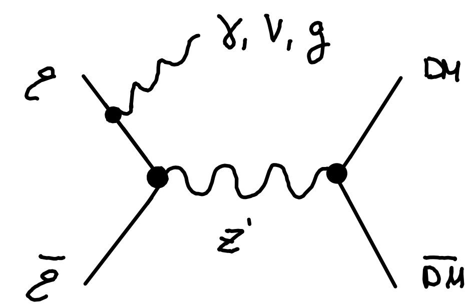
Theories





Mono-object + missing energy

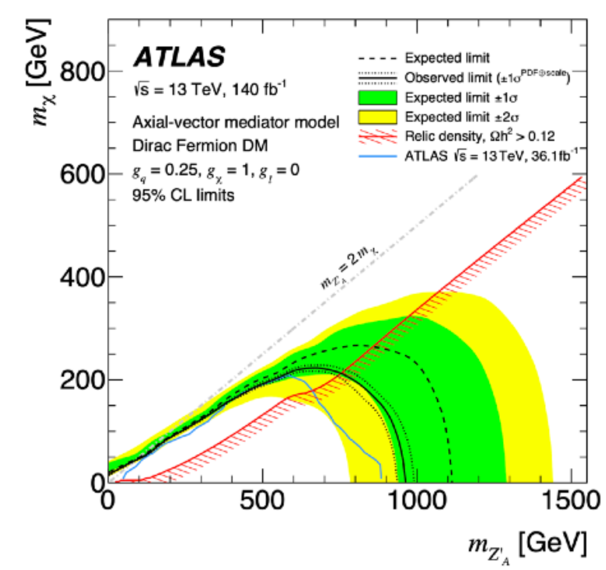
pp → Mediator* → DM $\overline{\text{DM}}$ + something



Simplified models

e.g.(pseudo)scalar, (axial)vector

[ATLAS, Dec ’24]



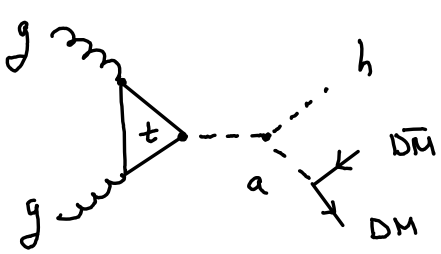
Particular UV completion

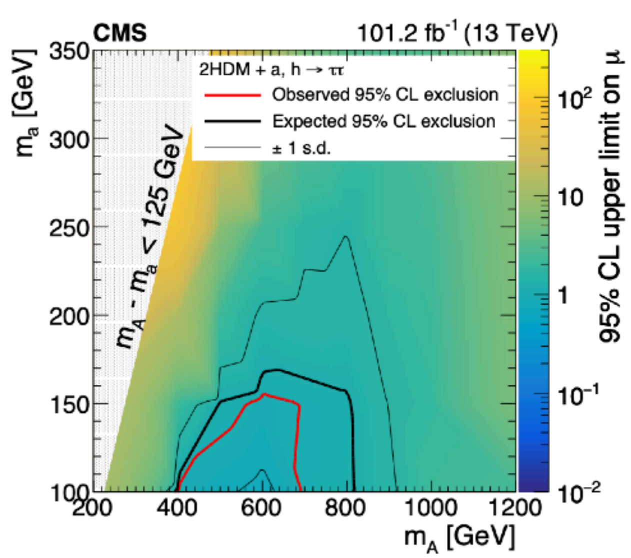
e.g. SUSY, nu-MSM, 2HDM+a…

[Julia Ziegler today]

[Yury Kolomensky on Thu]

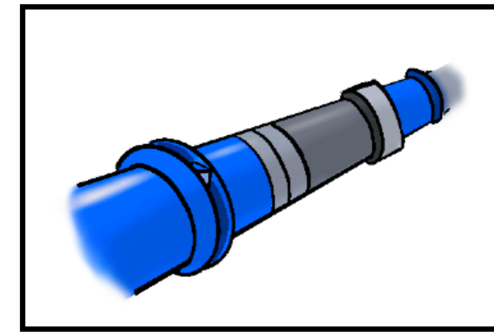
[CMS, June ’25]



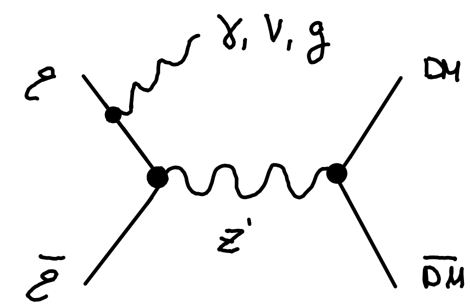


Collider searches

Theories



10^{-22} eV … eV GeV TeV … …



Mono-object + missing energy

pp → Mediator* → DM $\overline{\text{DM}}$ + something

Dijet resonances

Higgs invisible decay

Dark photons

Dark Higgs

Dark showers

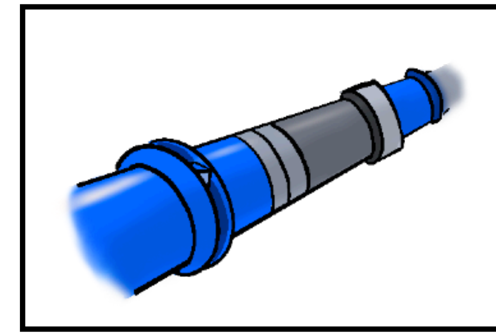
Heavy flavour + DM

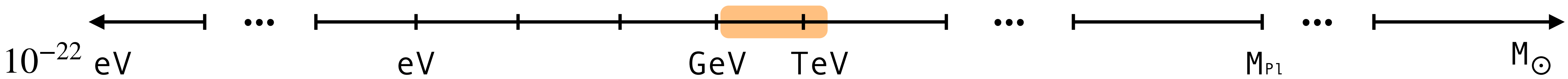
ALPS

…

[@Belle & Belle-II: Eiasha Washeed on Thu]

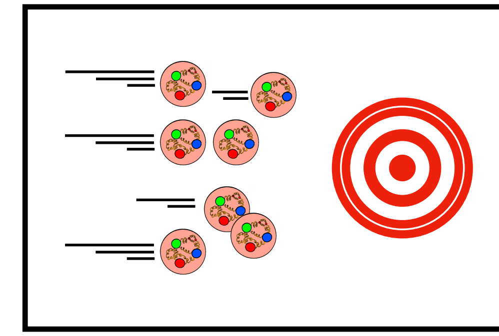
Collider searches

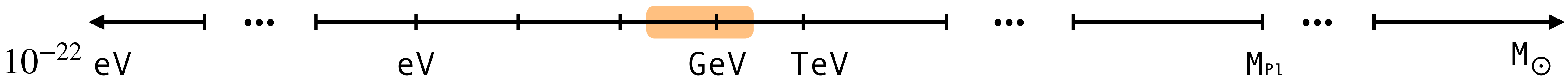


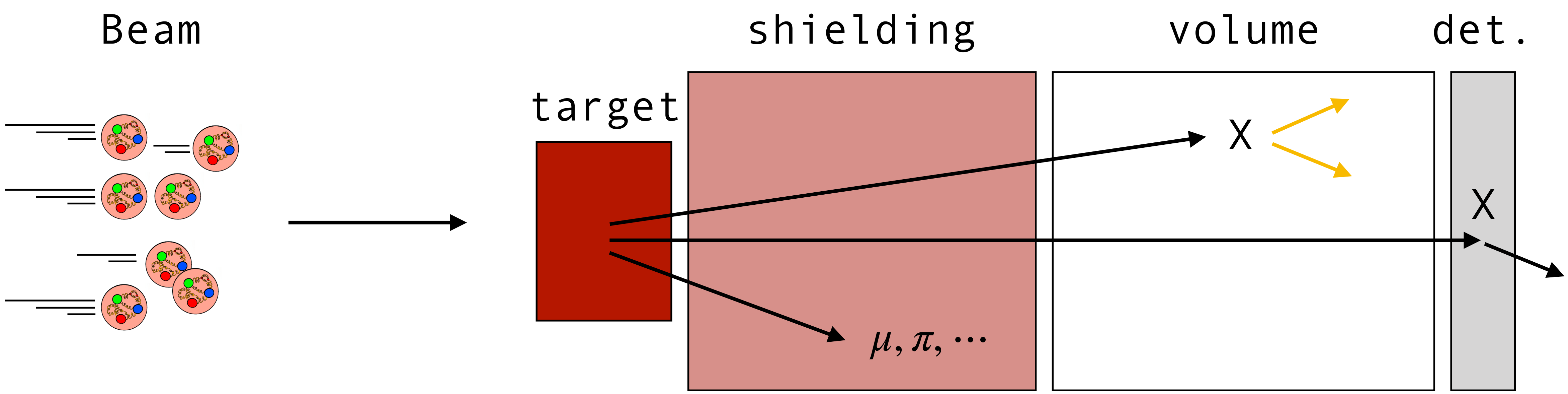


Energy frontier

Accelerator-based probes



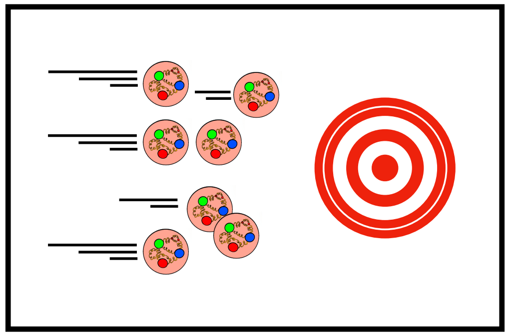


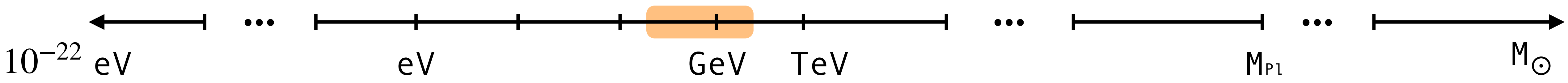


INTENSITY frontier

Accelerator-based probes

[Maksym Ovchynnikov on Mon]

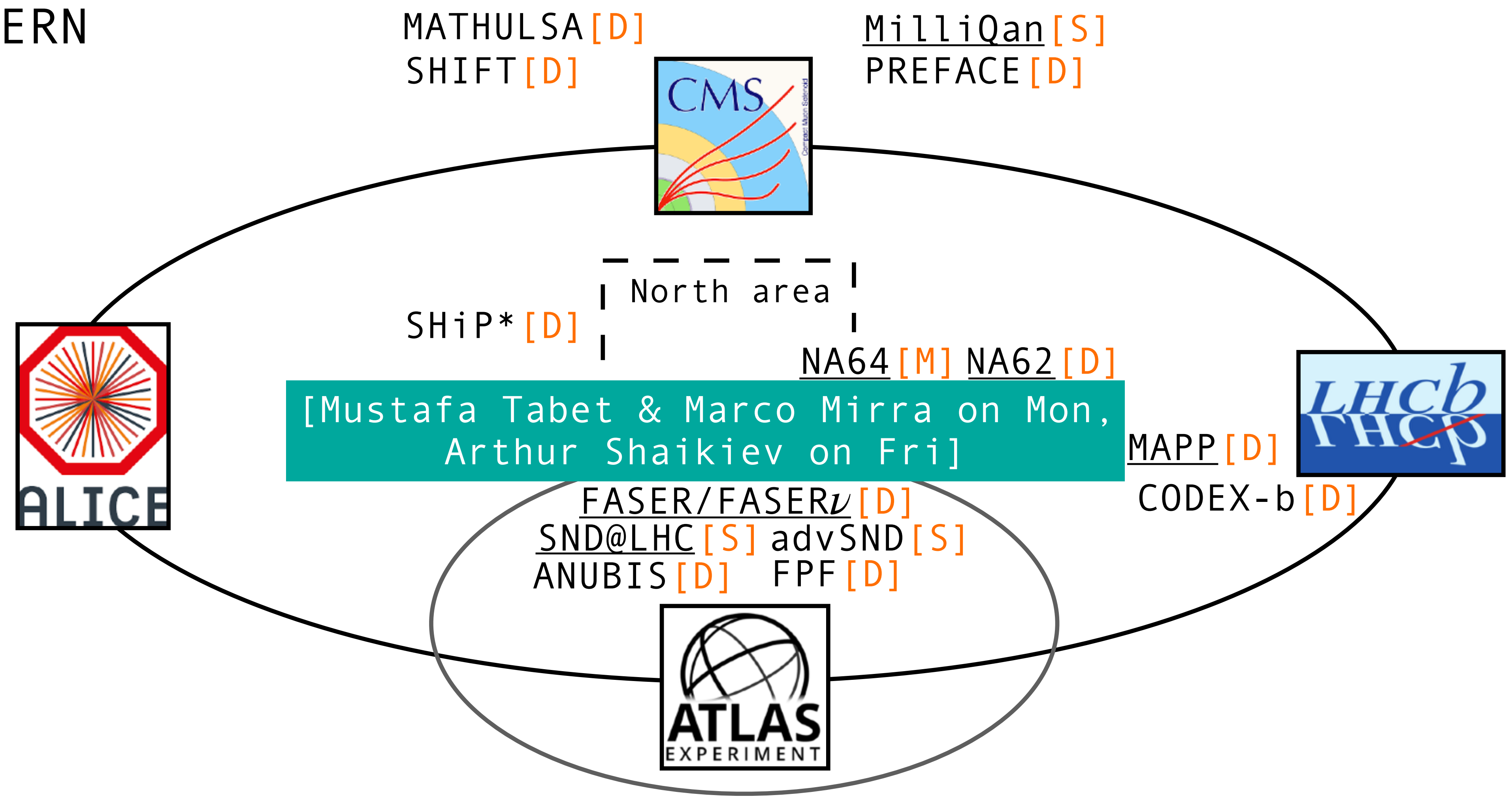




e.g. those @ CERN

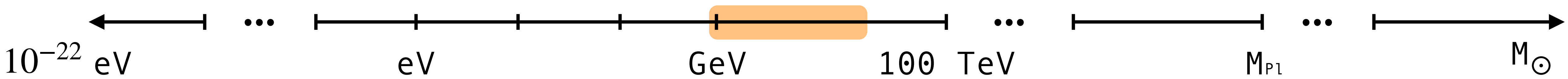
STATUS
running
proposed
approved*

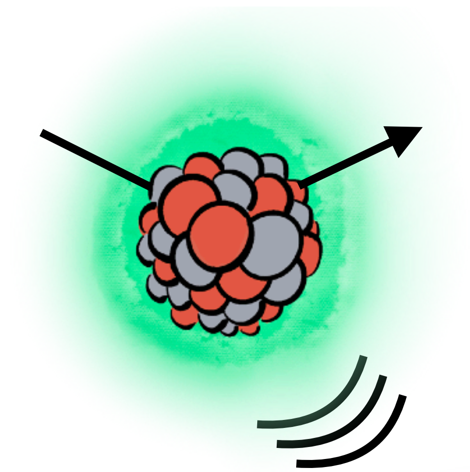
SIGNATURE
scatterings [S]
decays [D]
missing Energy [M]



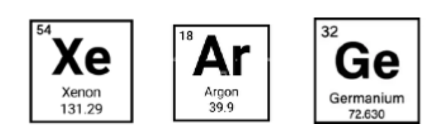
[see M. Ovchynnikov @ European Strategy ’25]

“Traditional” direct detection





Nuclear recoil
PTM exp.



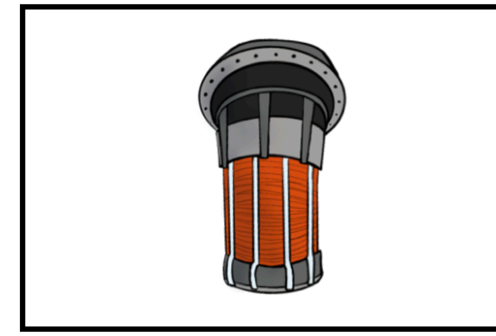
...

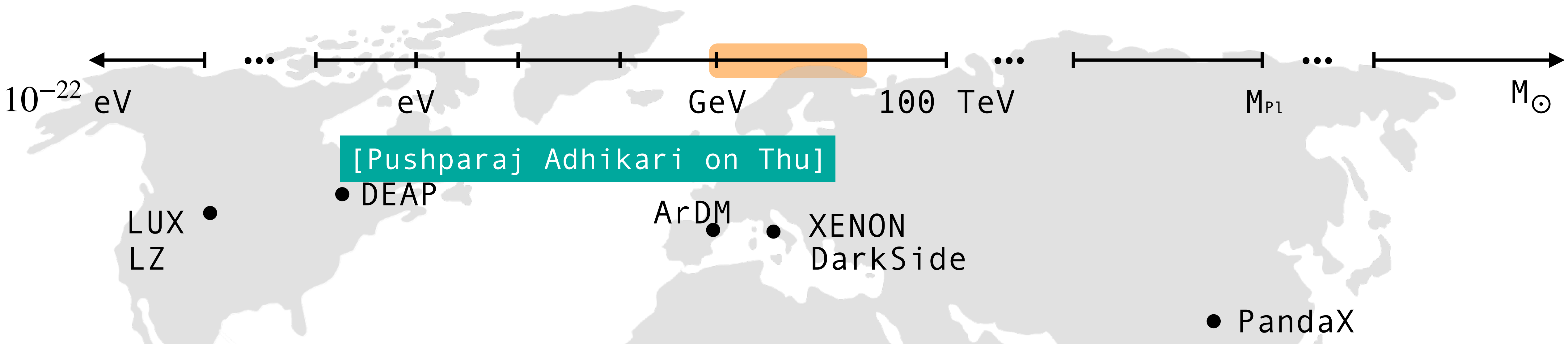
~keV energy resolution

LZ, PandaX,
XENON,
DarkSide,
DEAP…

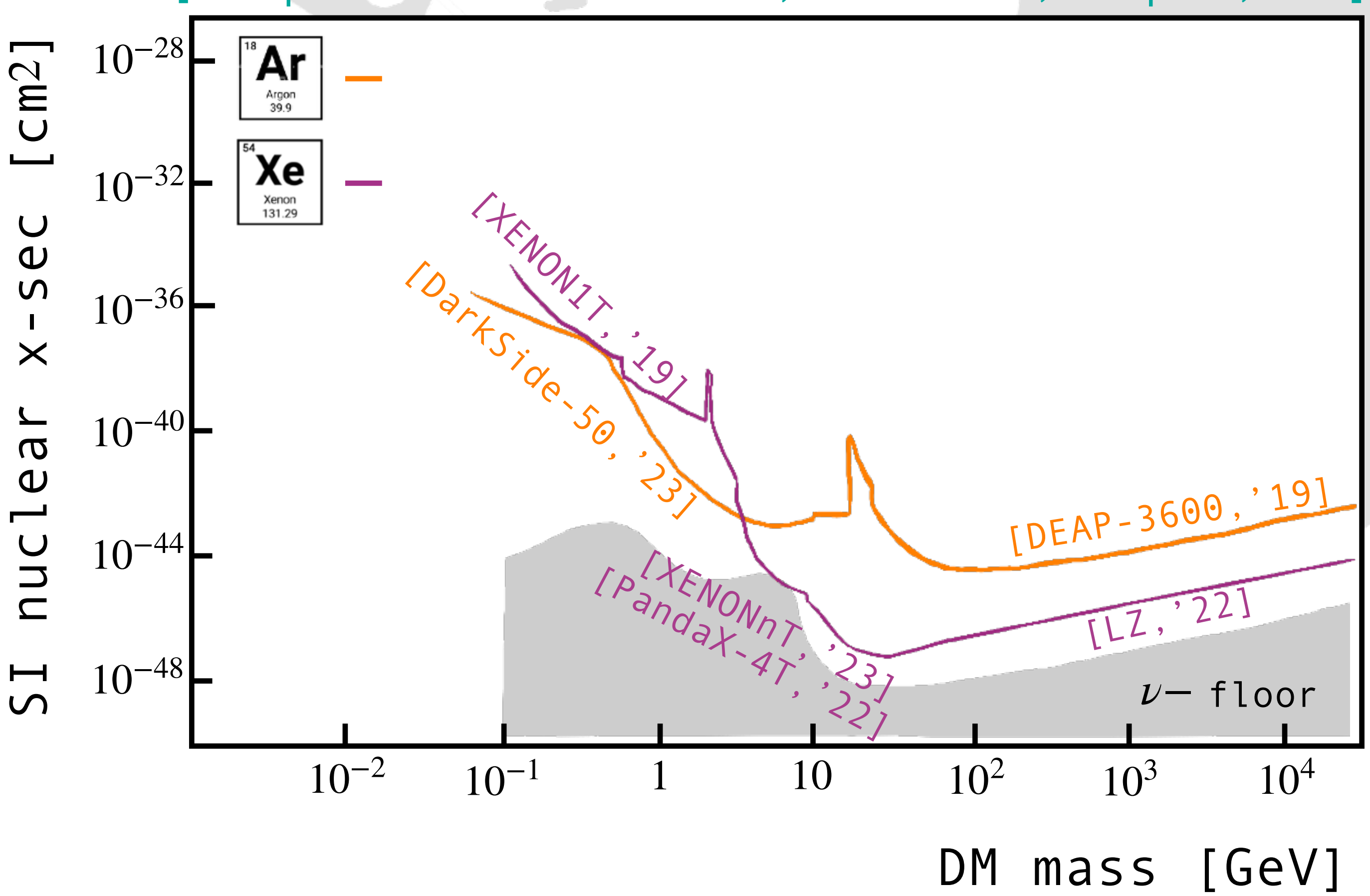
Direct detection

nuclear recoil



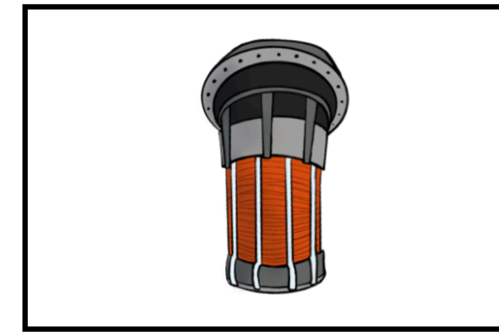


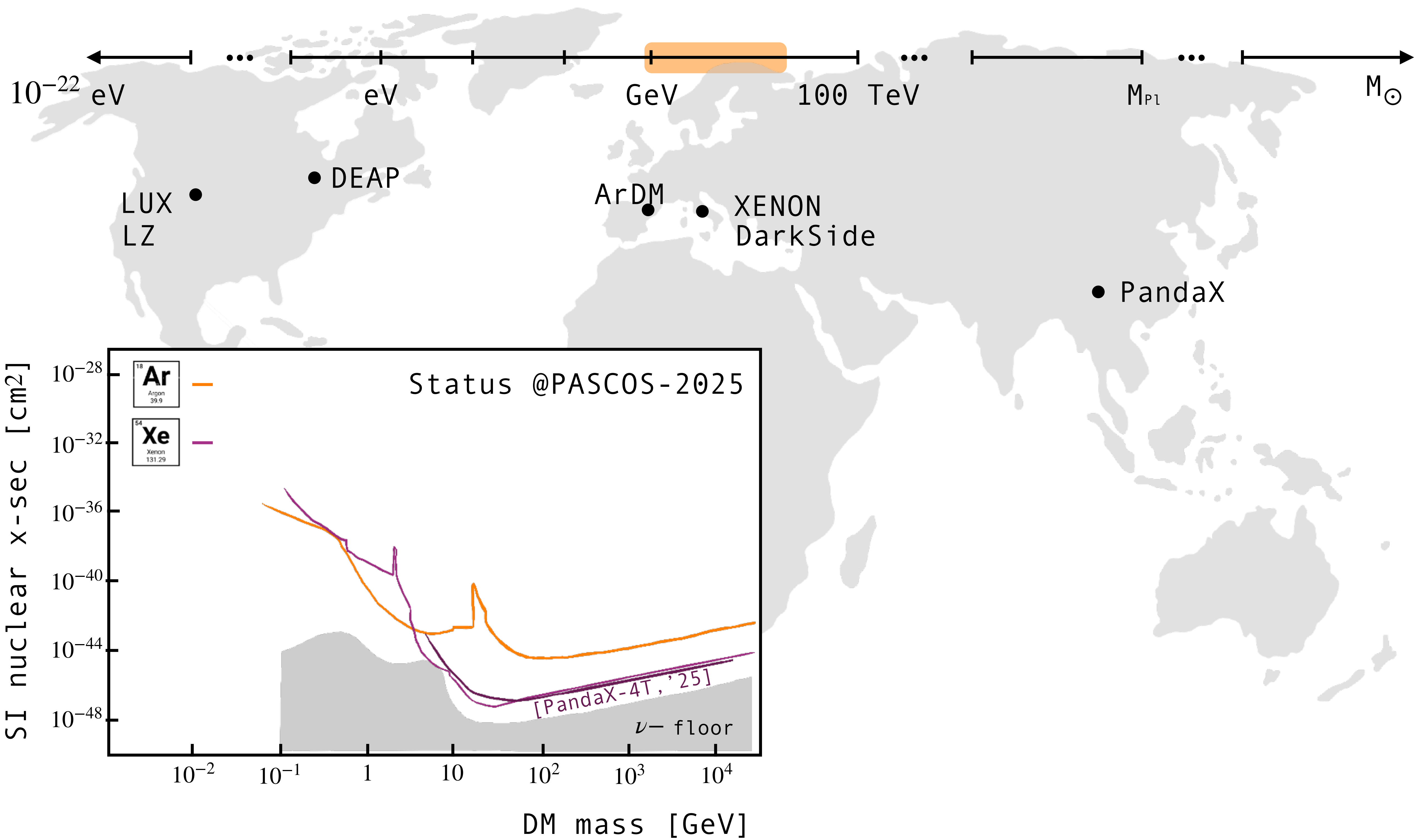
[adapted from Cirelli, Strumia, Zupan, '24]



Direct detection

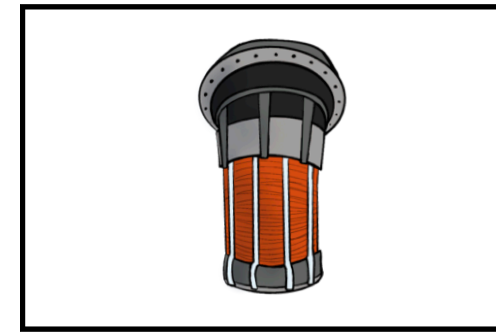
nuclear recoil

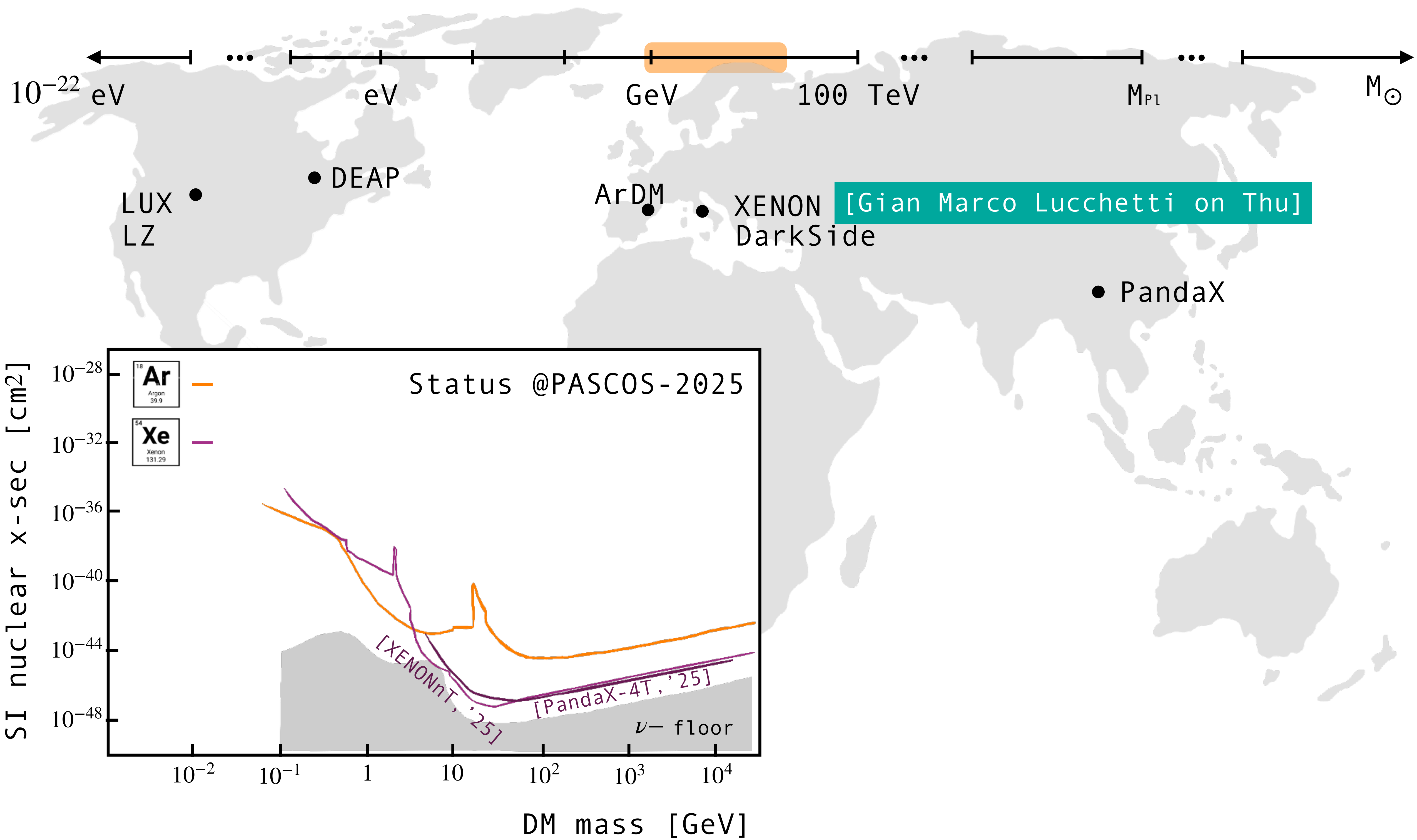




Direct detection

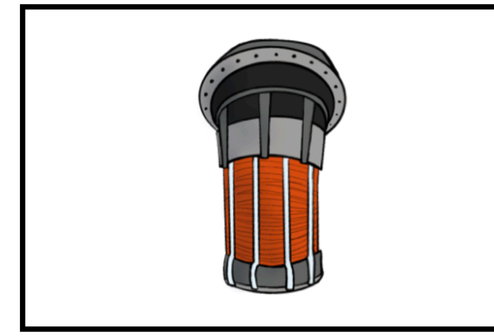
nuclear recoil

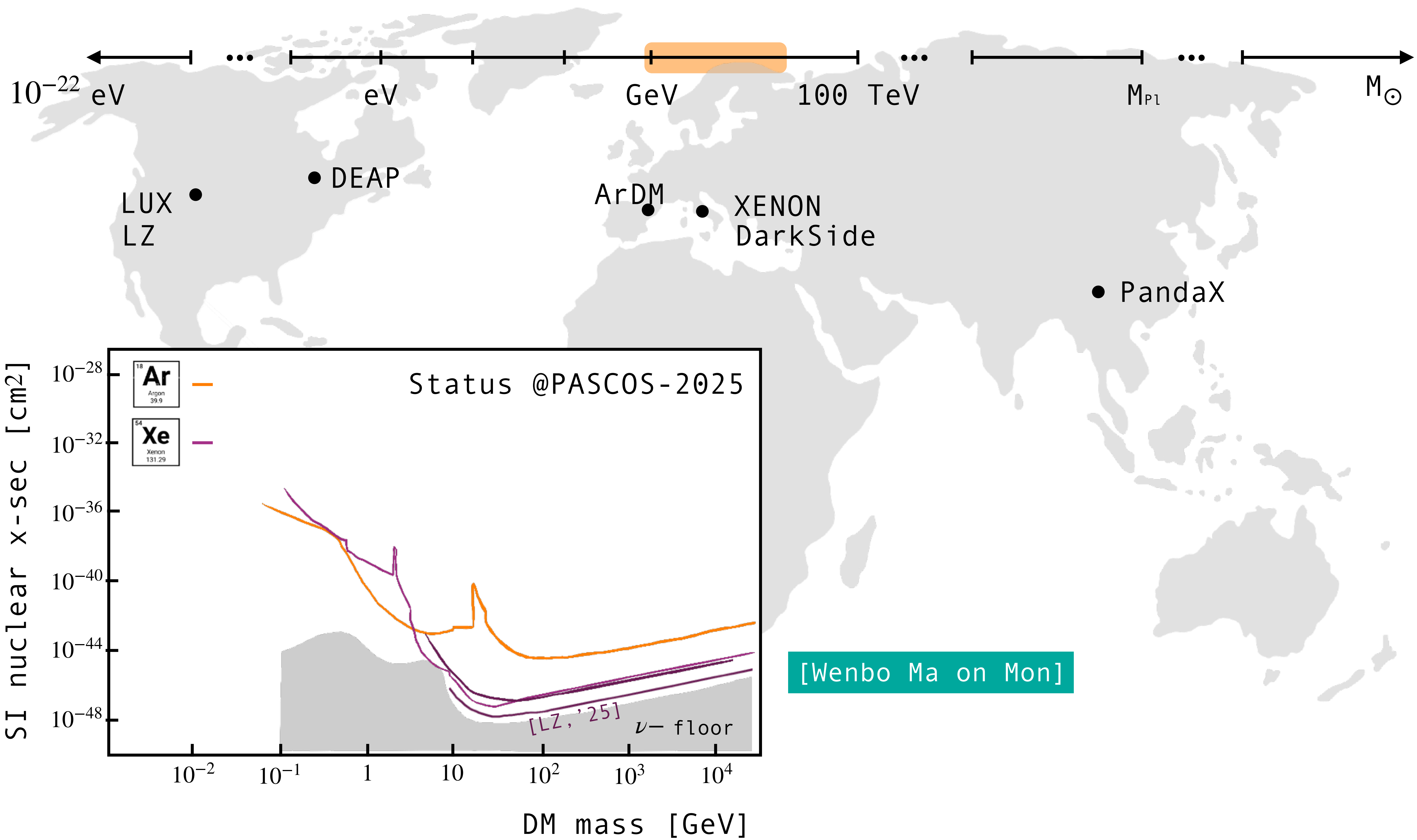




Direct detection

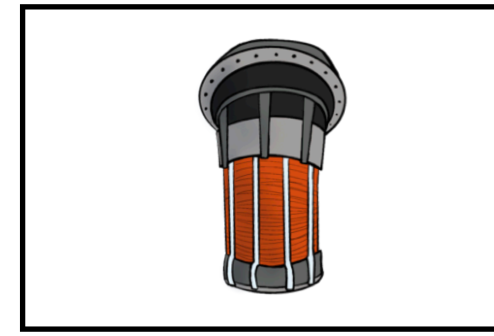
nuclear recoil

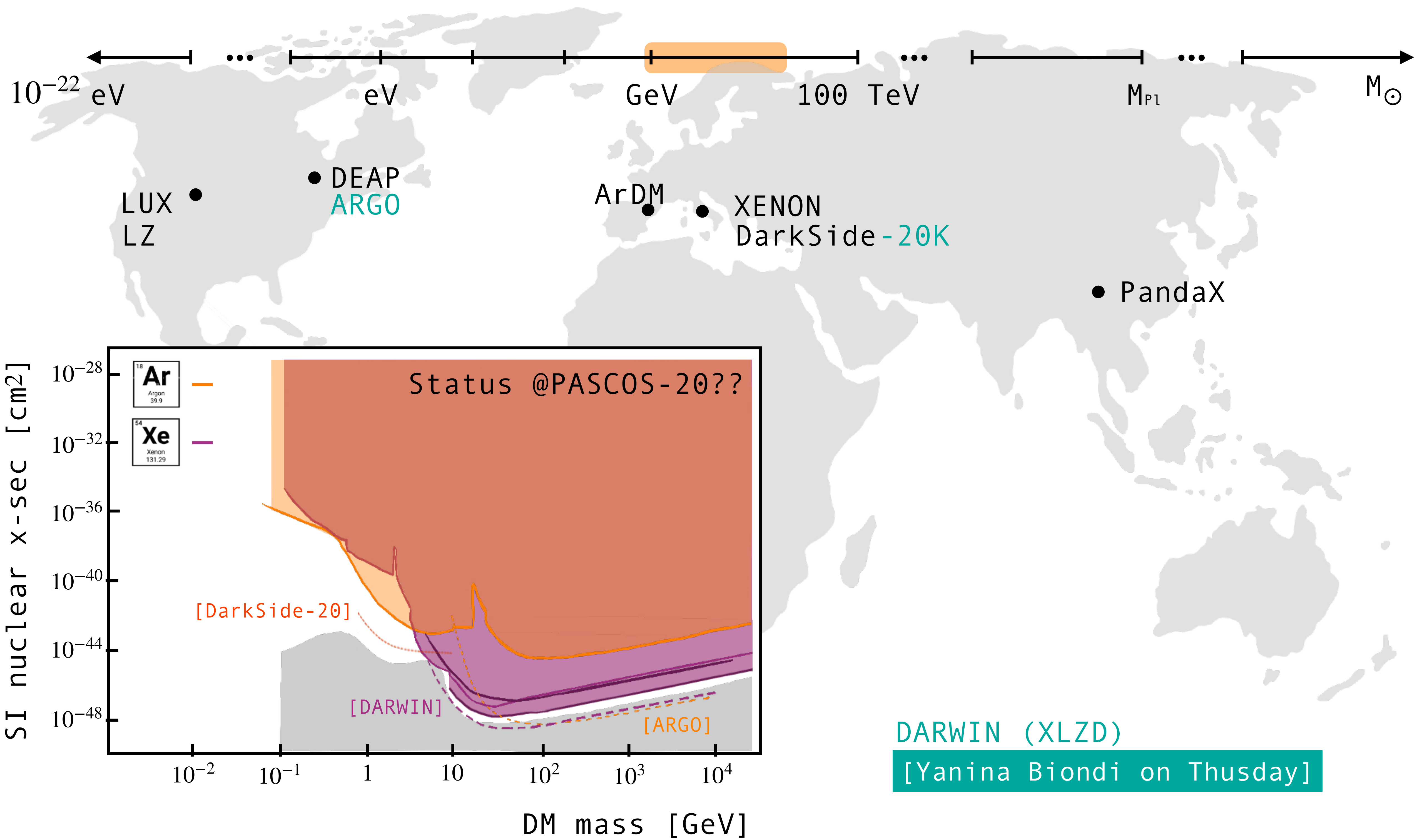




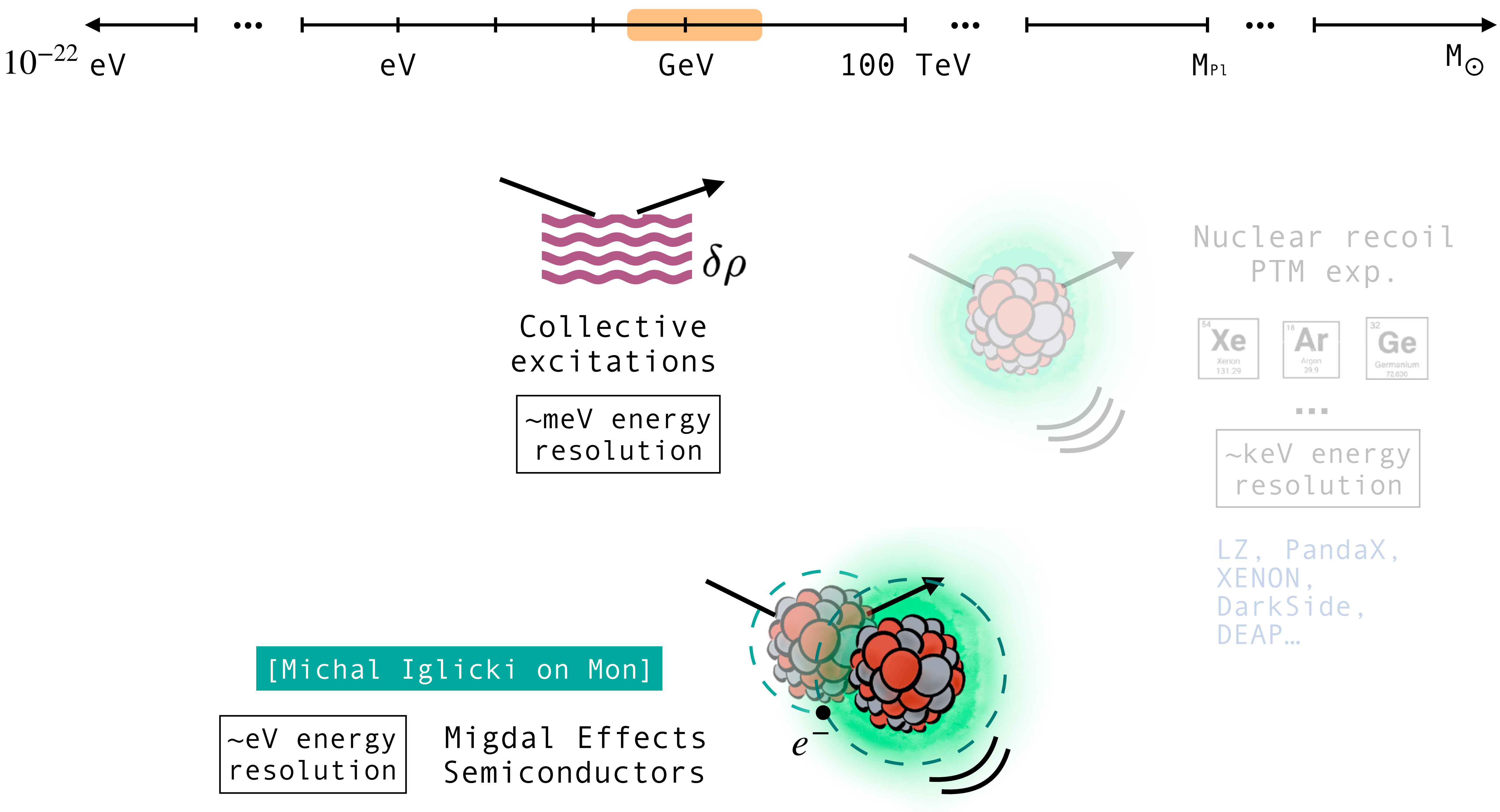
Direct detection

nuclear recoil



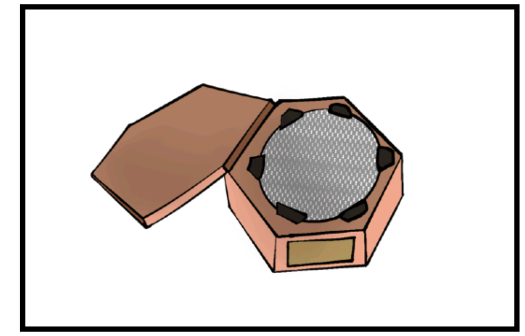


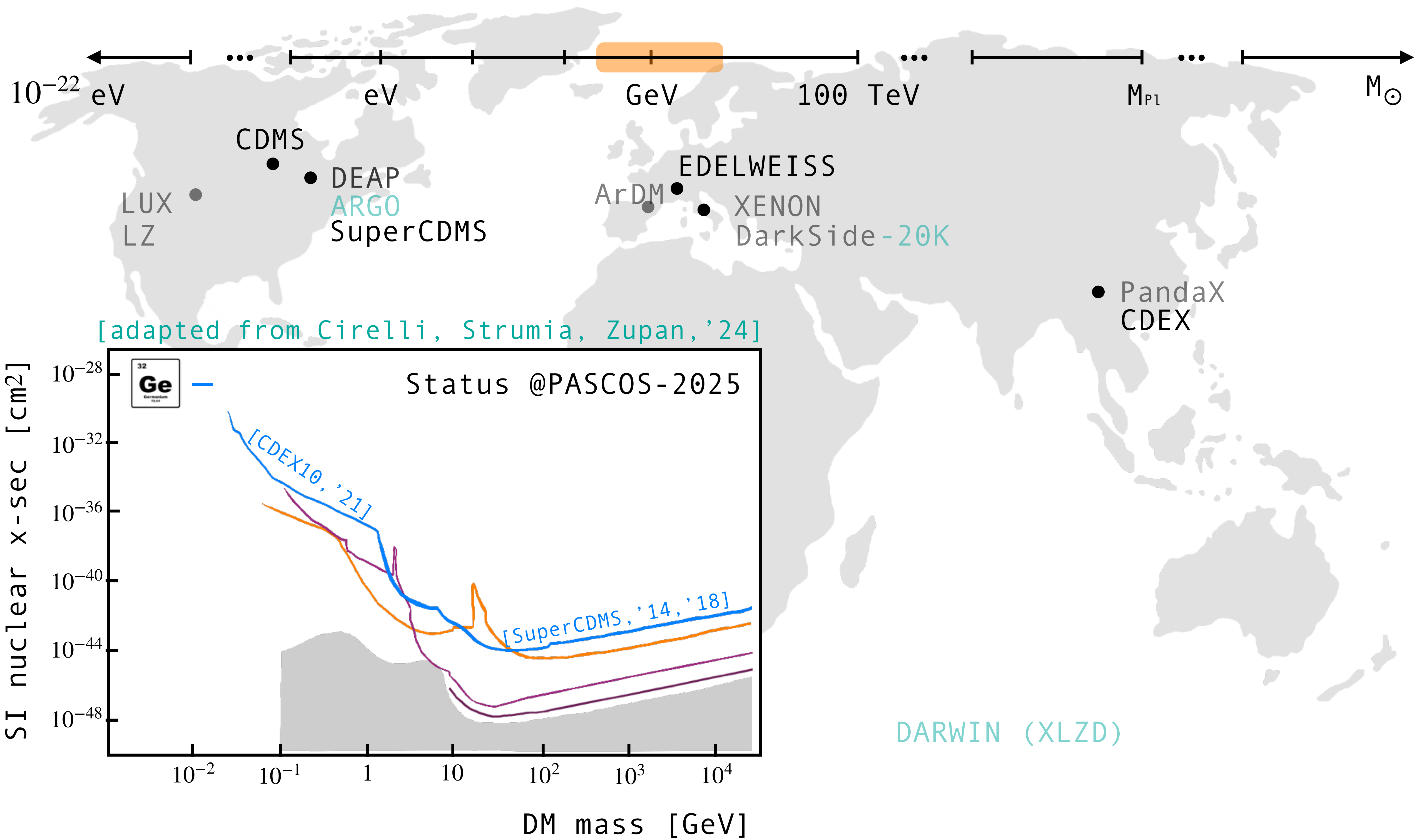
Direct detection



Direct detection

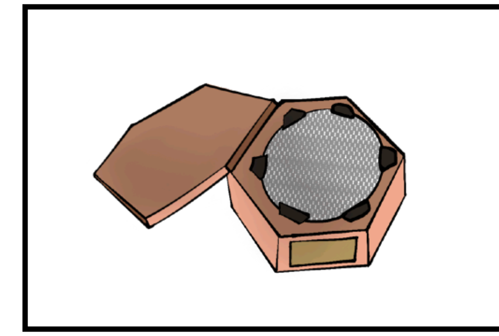
light dark matter

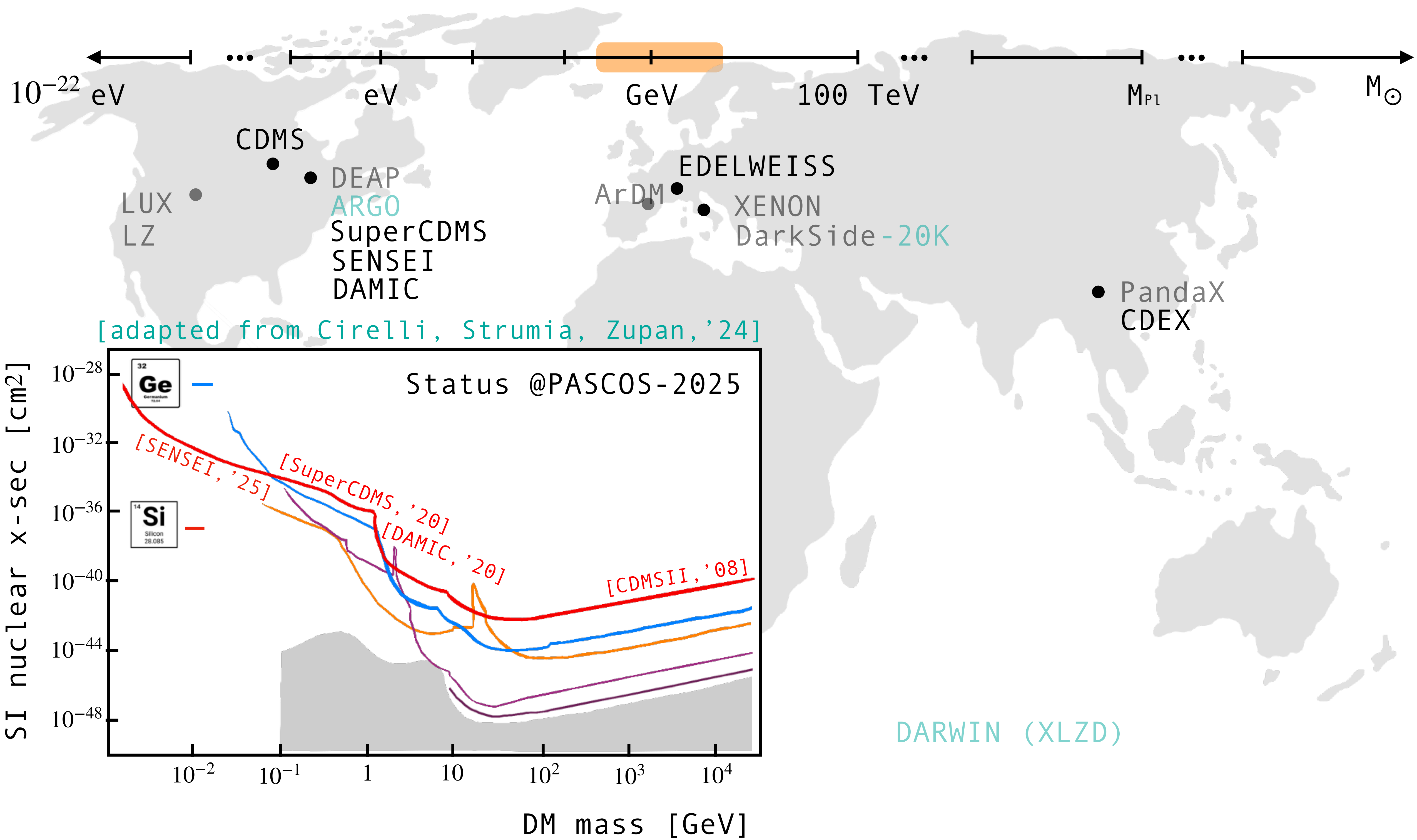




Direct detection

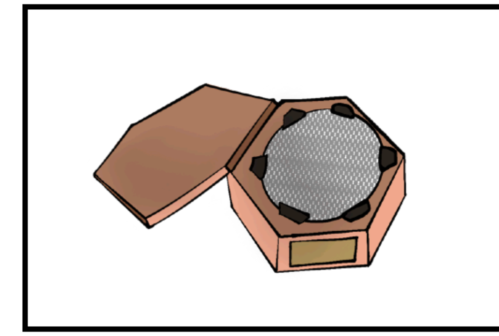
light dark matter

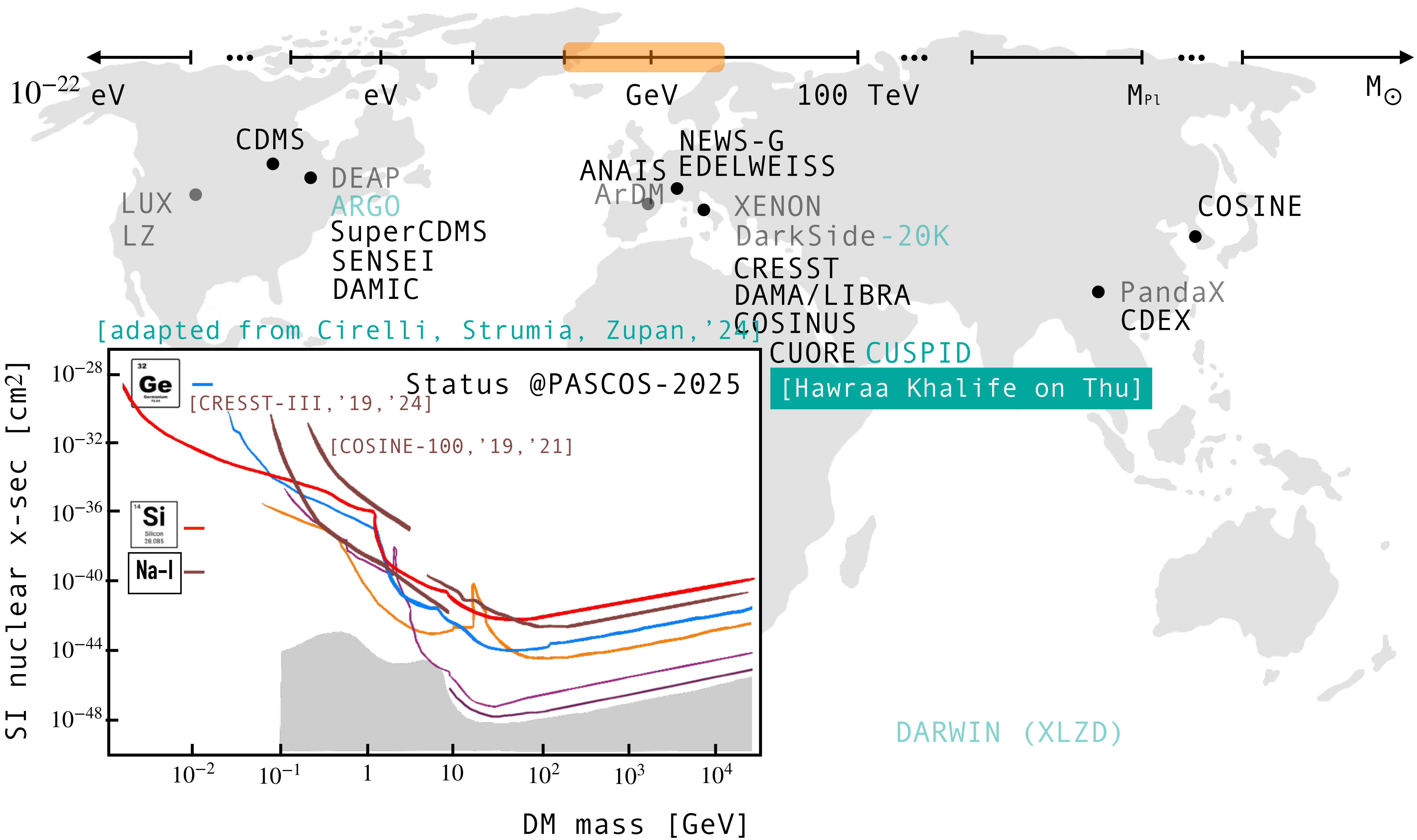




Direct detection

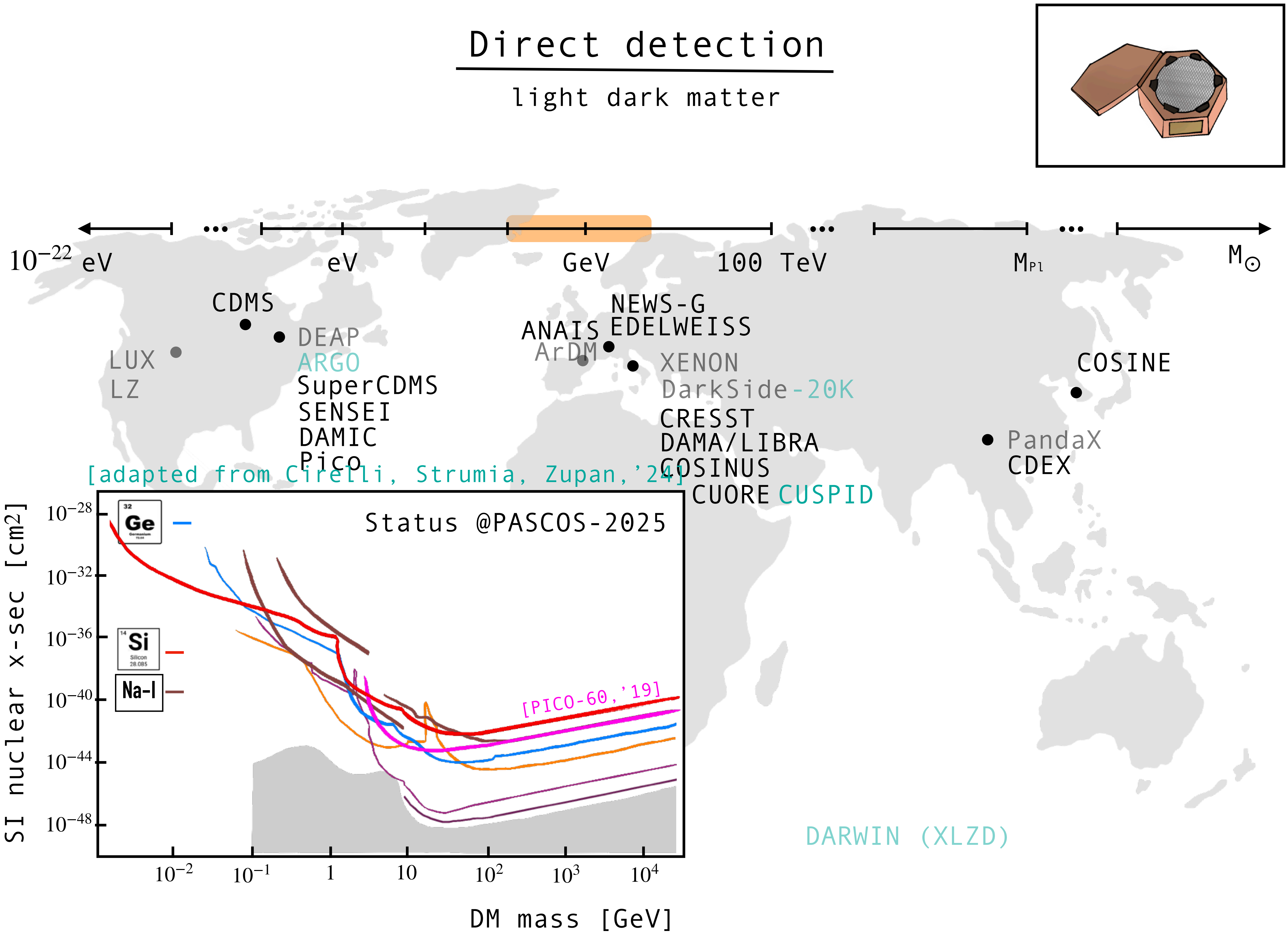
light dark matter





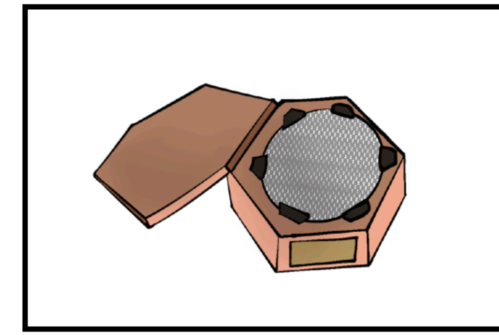
Direct detection

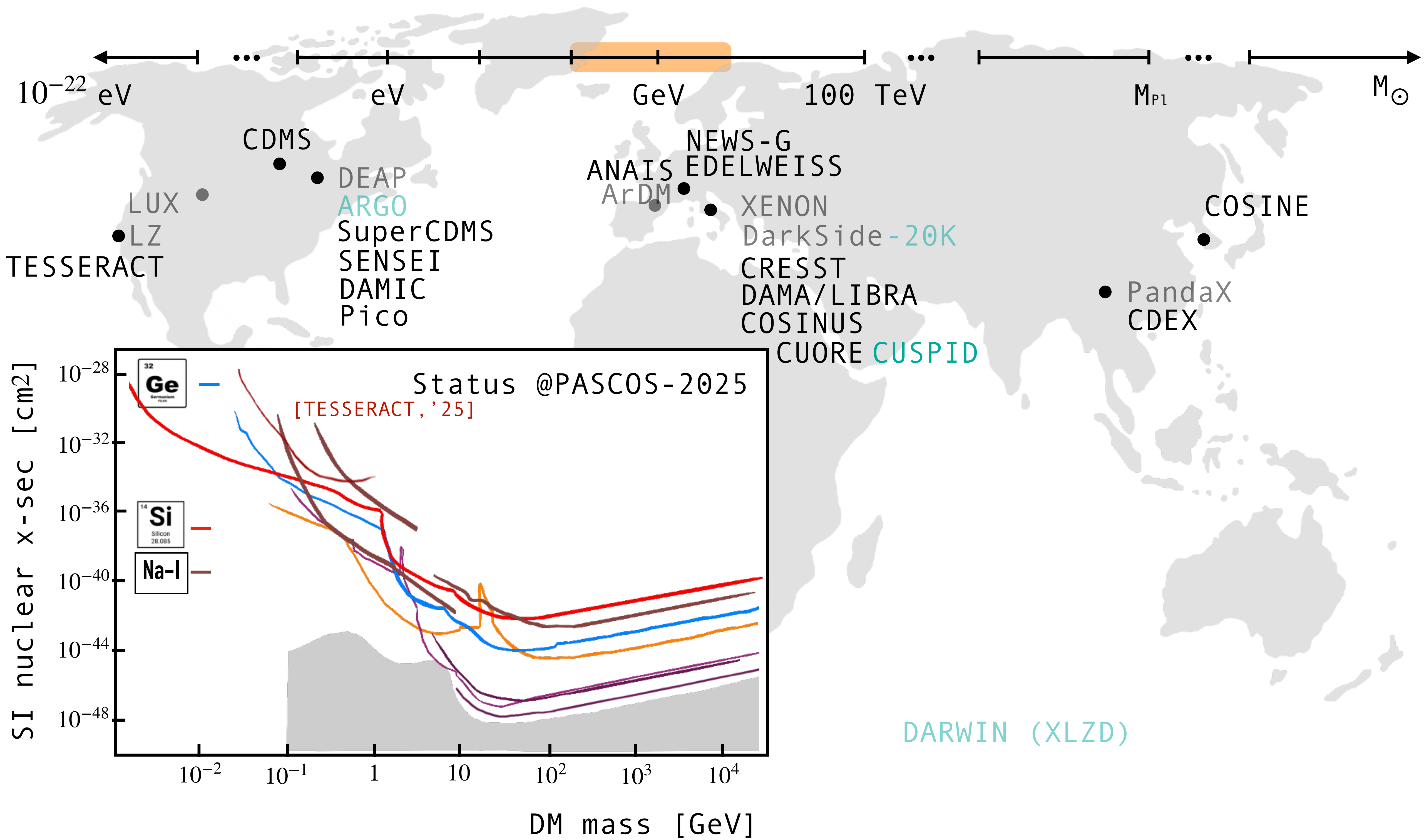
light dark matter



Direct detection

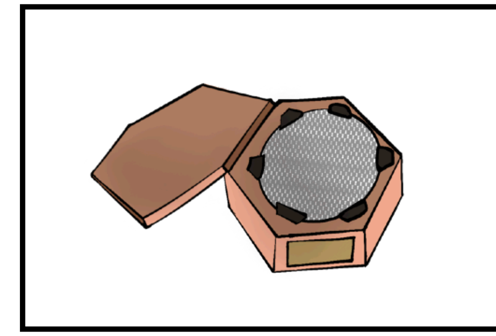
light dark matter

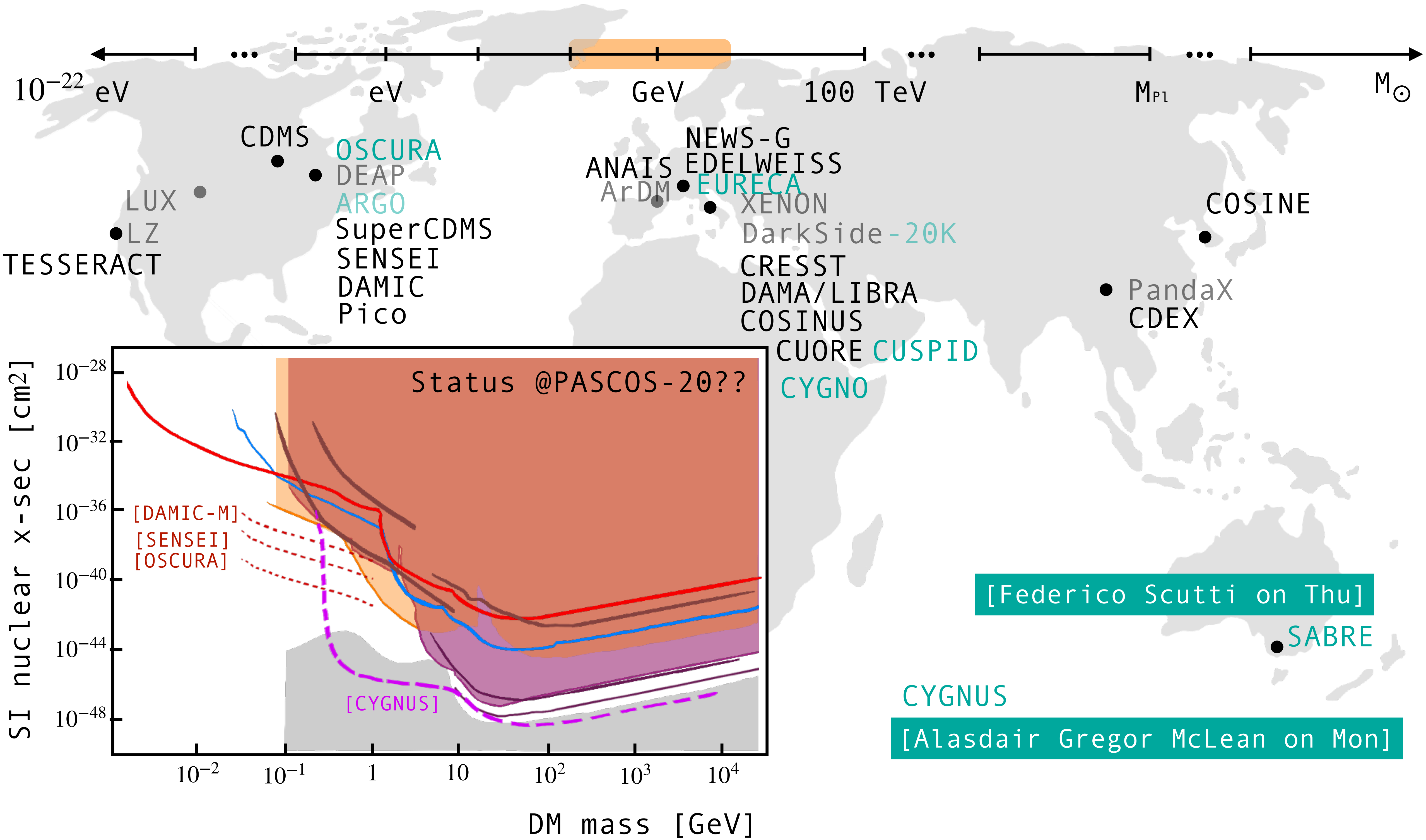




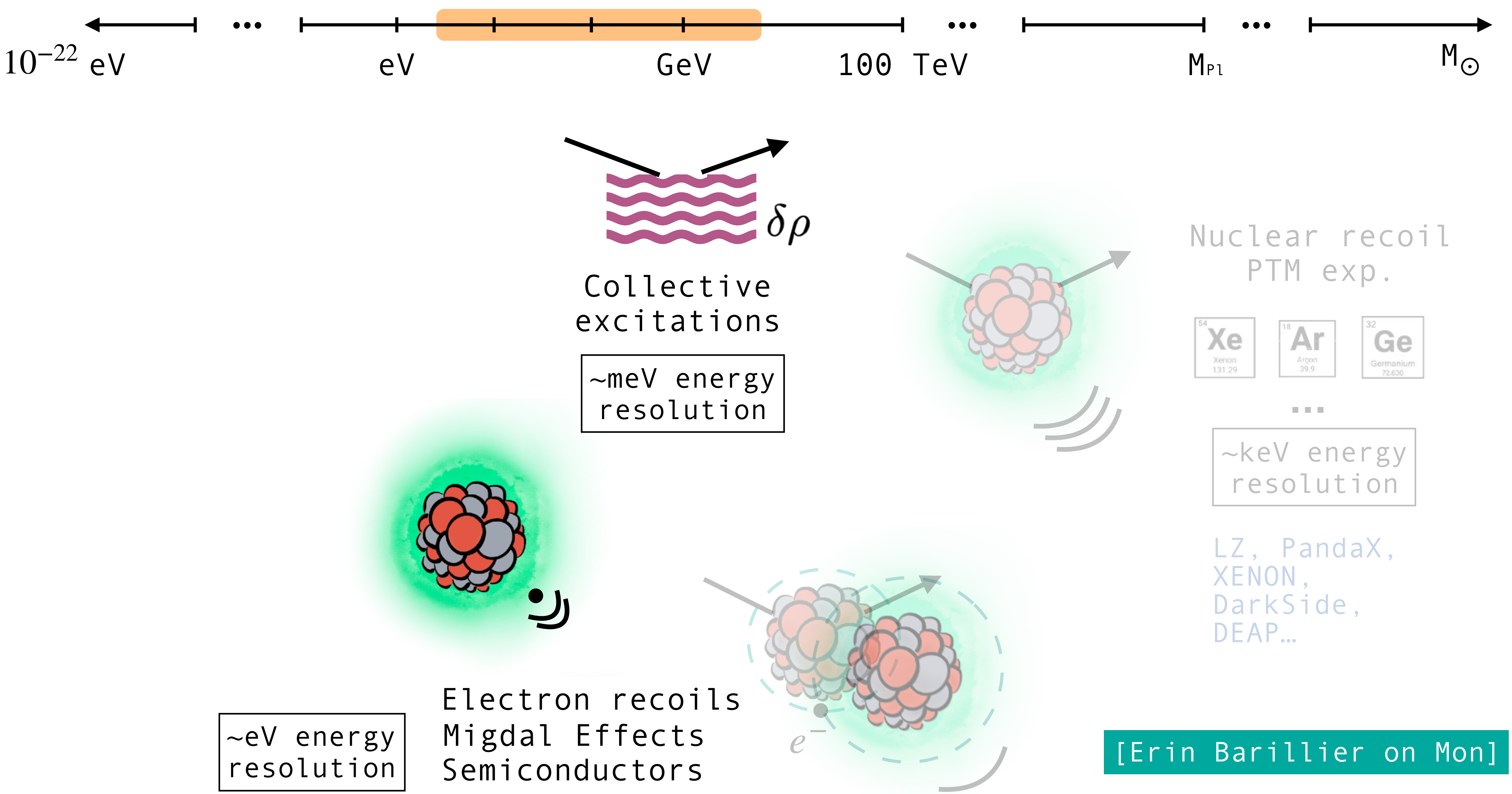
Direct detection

light dark matter

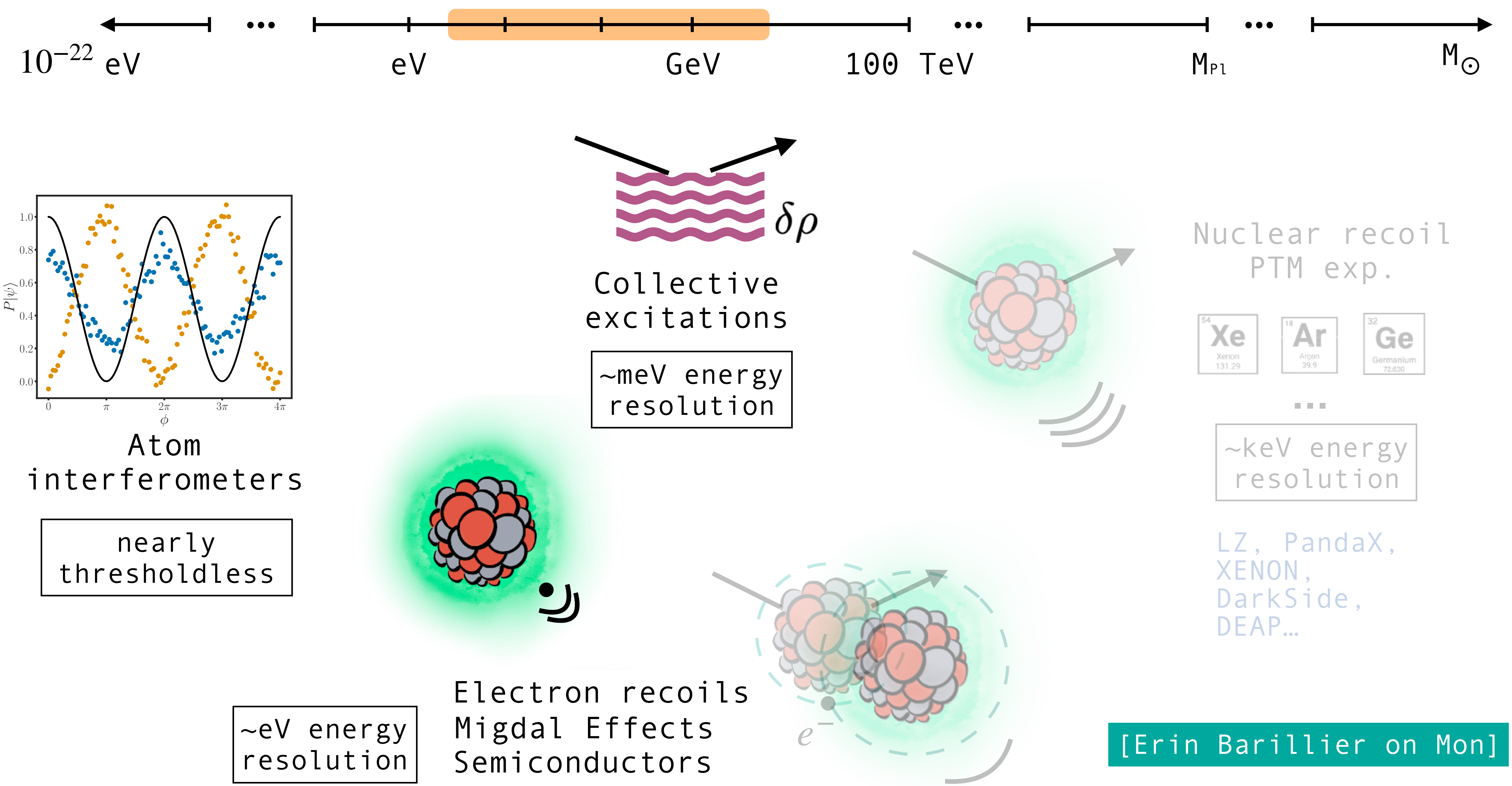




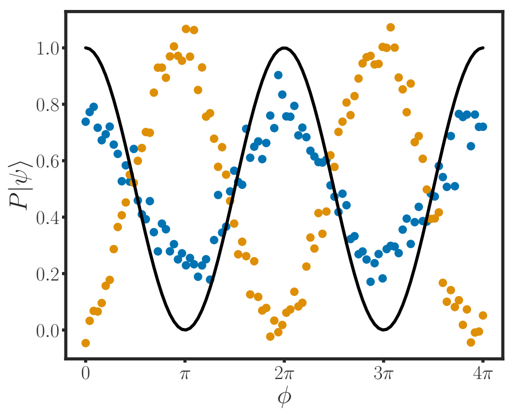
Direct detection



Direct detection



Quantum sensors

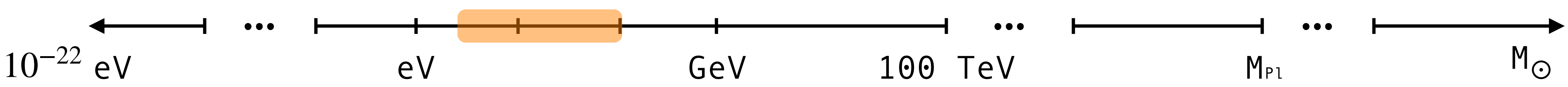


Atom interferometers

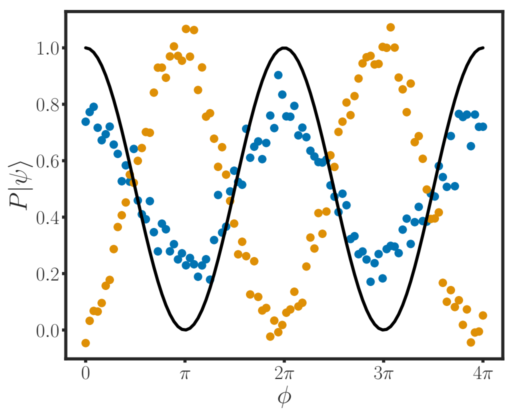
nearly thresholdless

Quantum sensors

coherent enhancements

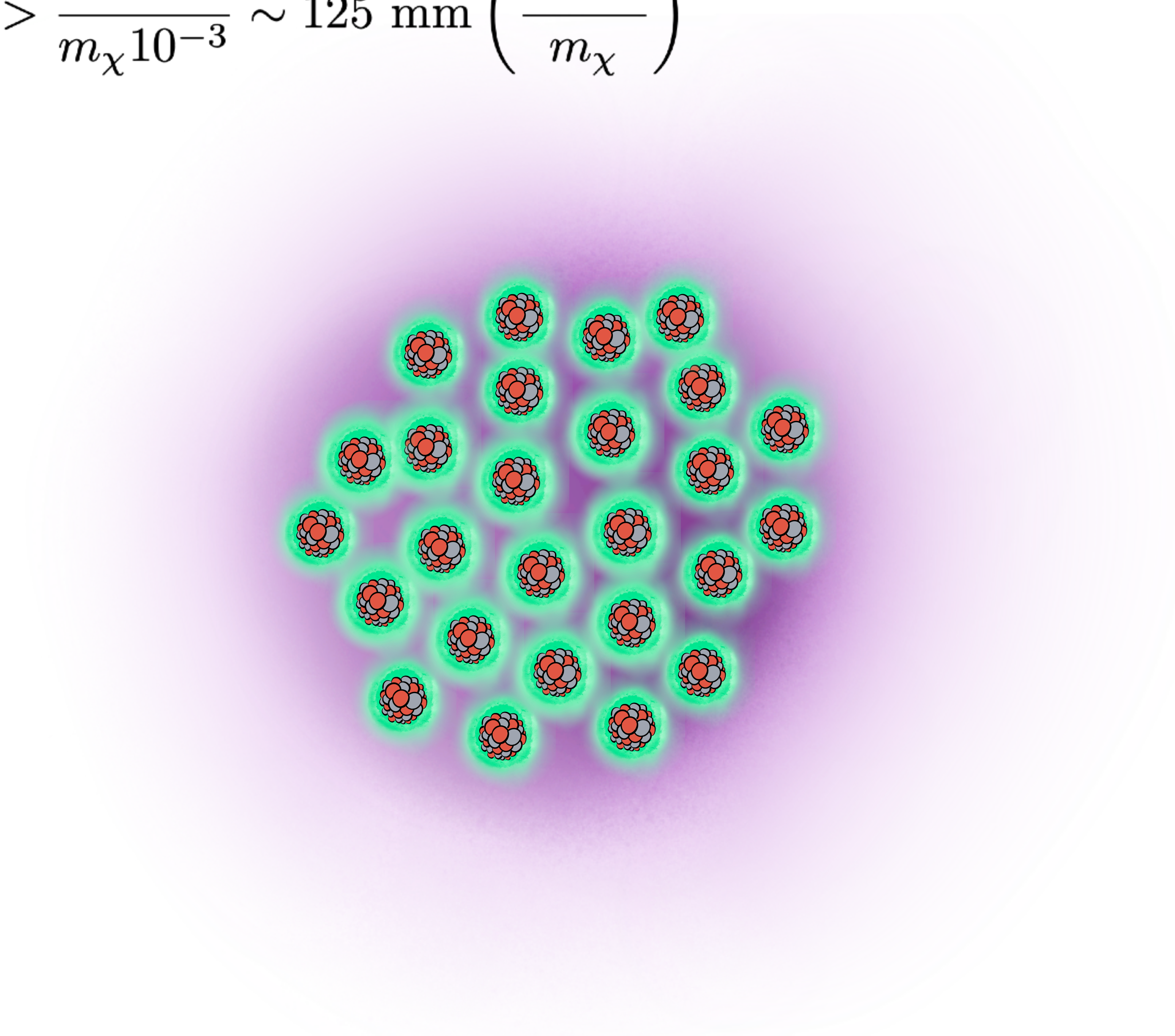


$$\lambda = \frac{2\pi}{q} > \frac{2\pi}{m_\chi 10^{-3}} \sim 125\ \mathrm{mm} \left(\frac{10\ \mathrm{eV}}{m_\chi}\right)$$



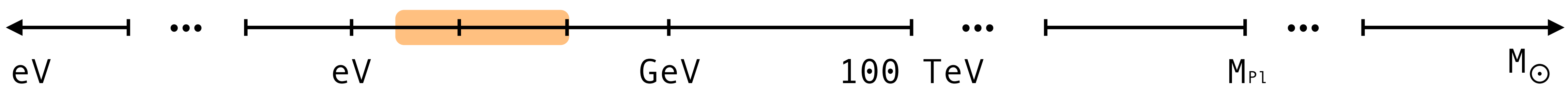
Atom interferometers

nearly thresholdless



Quantum sensors

coherent enhancements



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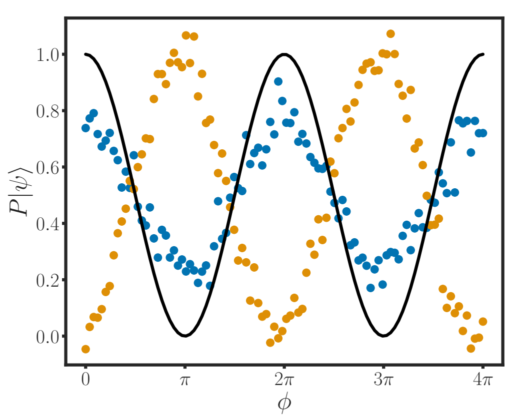
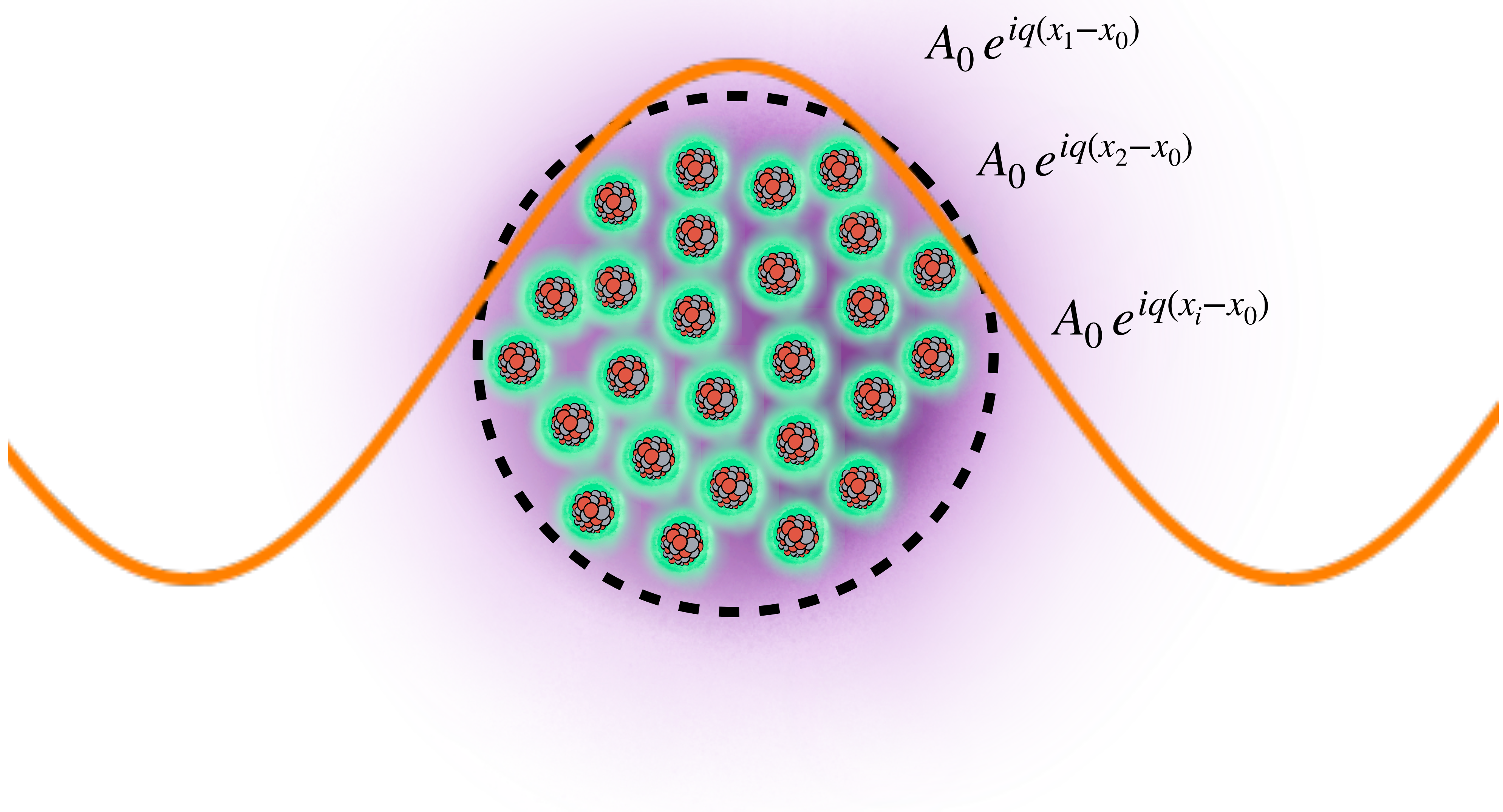


Atom interferometers

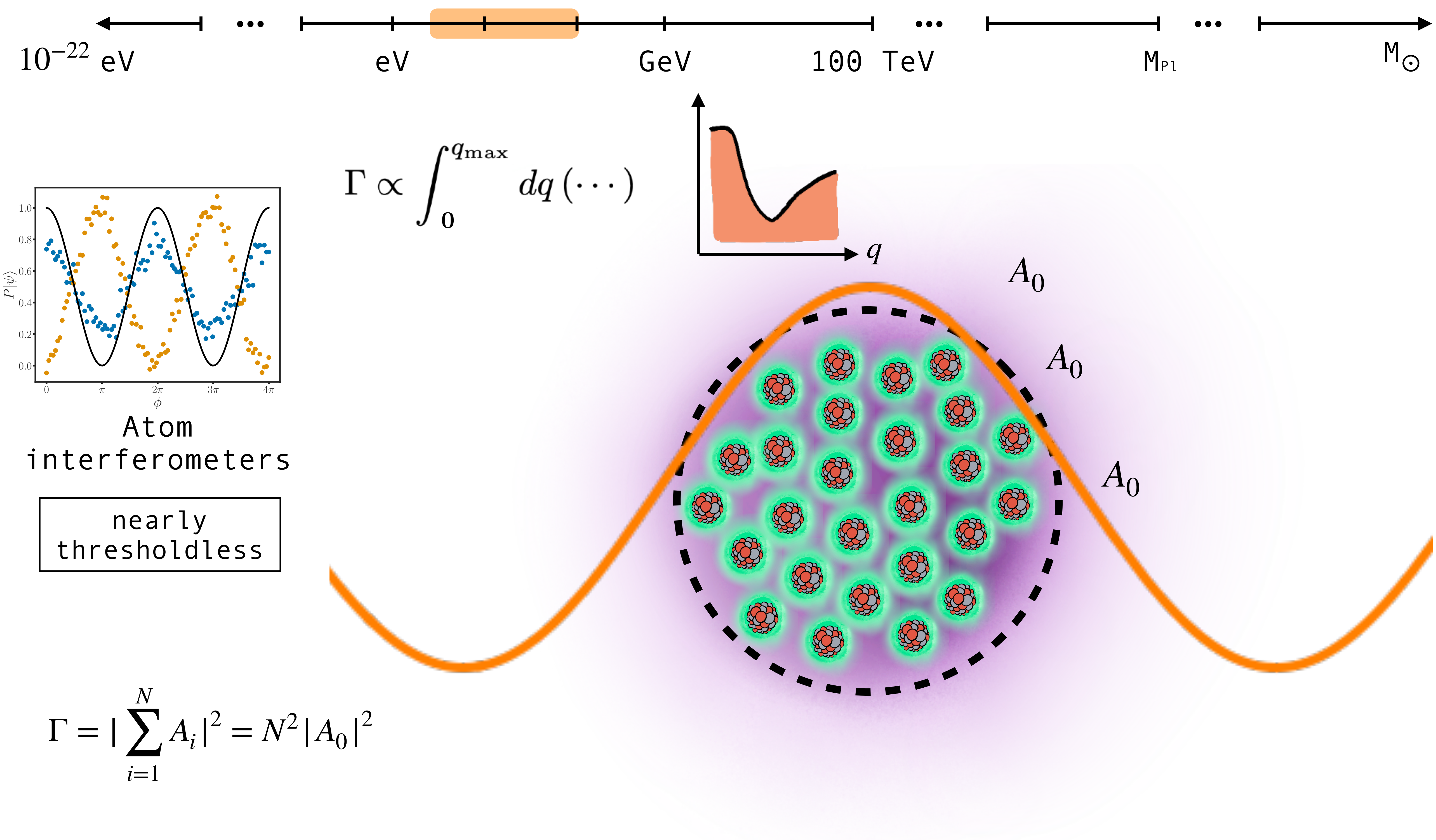
nearly thresholdless



$$\Gamma = |\sum_{i=1}^{N} A_i|^2$$

Quantum sensors

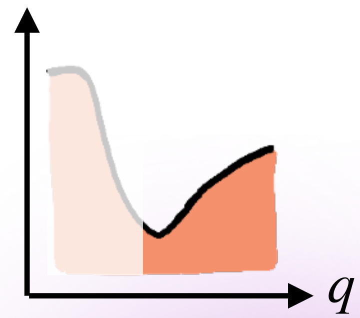
coherent enhancements

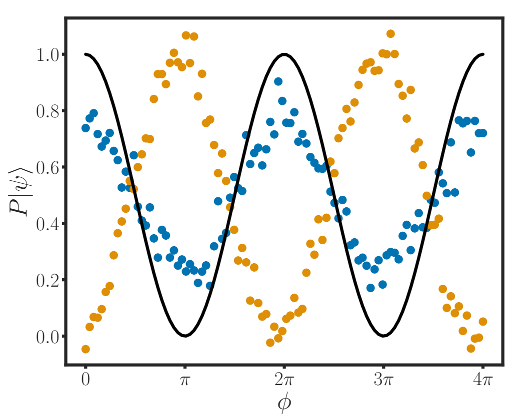


Quantum sensors

coherent enhancements

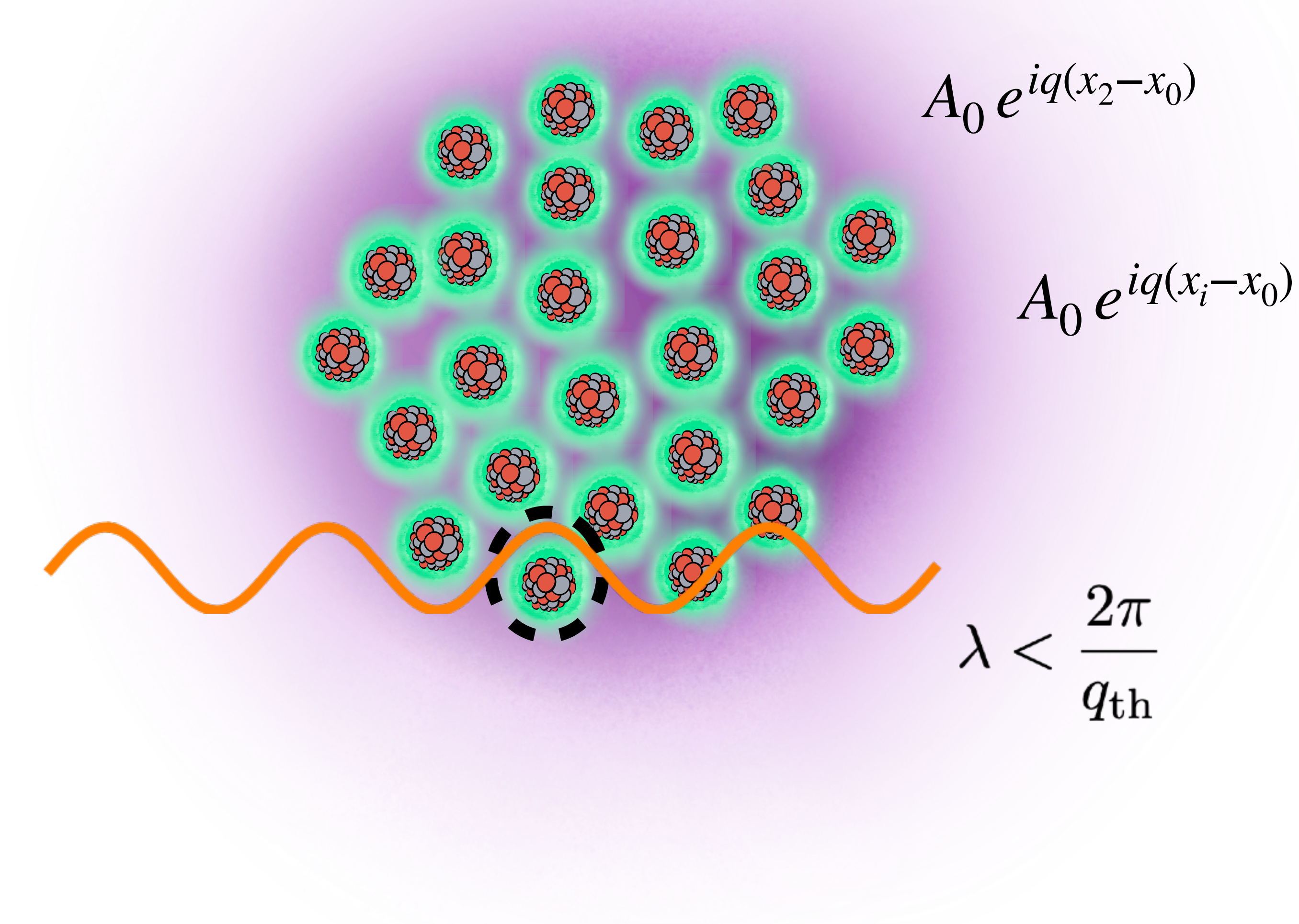
$$\Gamma \propto \int_{\mathbf{MeV}}^{q_{\max}} dq\,(\cdots)$$



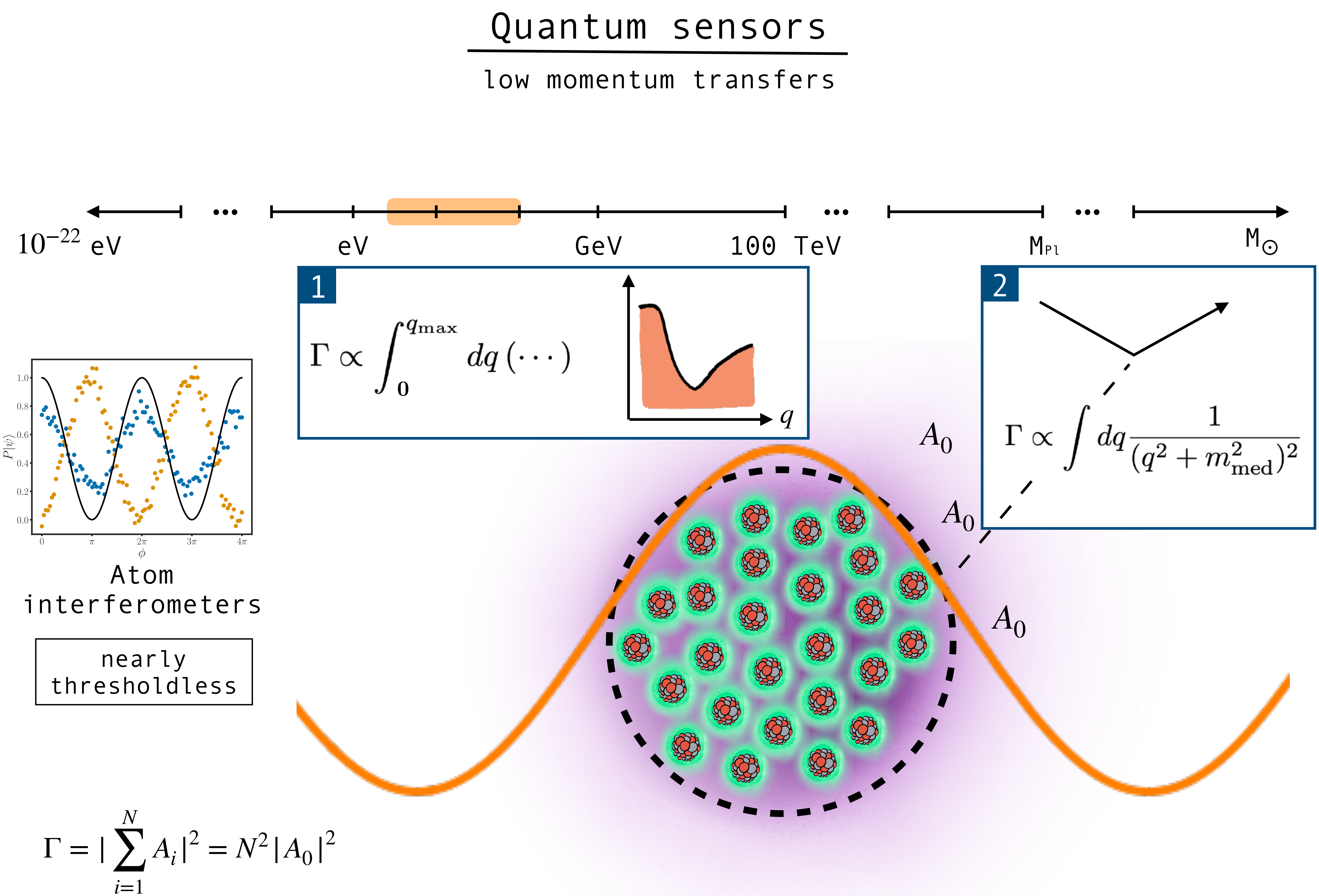


Atom interferometers

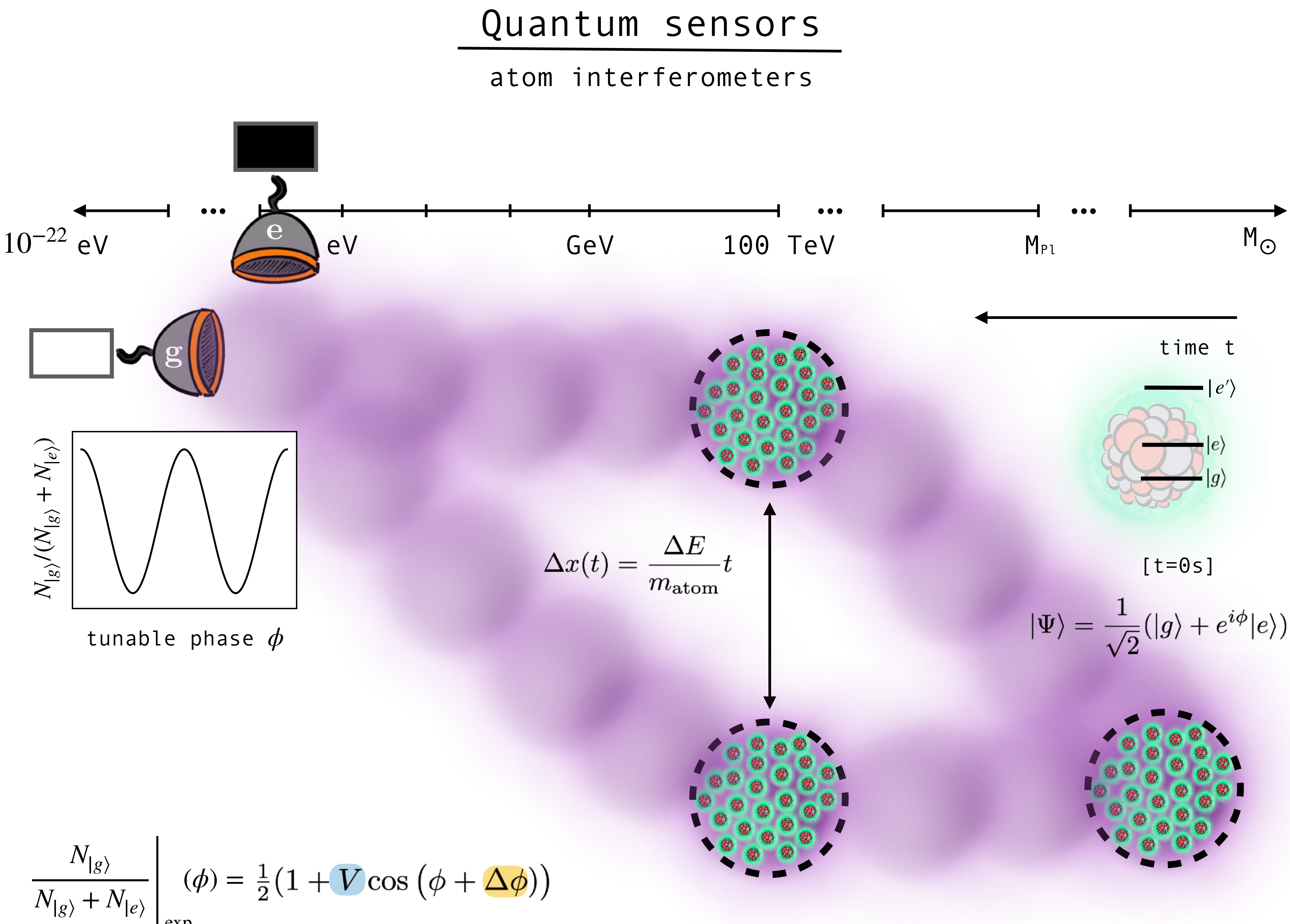
nearly thresholdless



$$\Gamma = |\sum_{i=1}^{N} A_i|^2 = N|A_0|^2$$

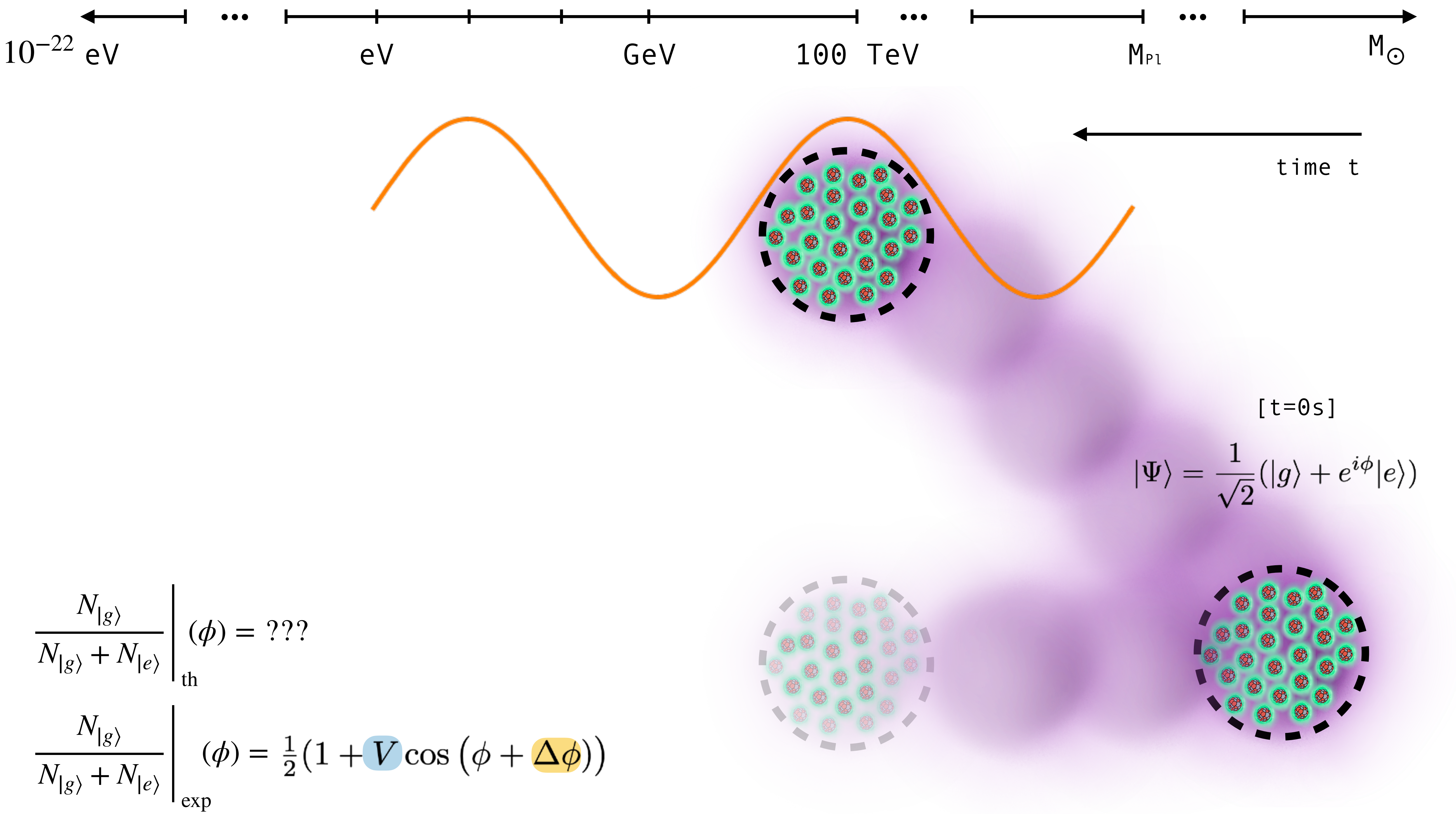


Quantum sensors
low momentum transfers
10^{-22} eV
eV
GeV
100 TeV
M_{Pl}
$M_{\odot}$
1
$\Gamma \propto \int_0^{q_{\max}} dq\,(\cdots)$
q
2
A_0
A_0
A_0
$\Gamma \propto \int dq \frac{1}{(q^2 + m_{\rm med}^2)^2}$
Atom interferometers
nearly thresholdless
$\Gamma = |\sum_{i=1}^{N} A_i|^2 = N^2 |A_0|^2$


Quantum sensors
atom interferometers
10^{-22} eV
eV
GeV
100 TeV
M_{Pl}
$M_{\odot}$
e
g
time t
$|e'\rangle$
$|e\rangle$
$|g\rangle$
[t=0s]
$|\Psi\rangle = \frac{1}{\sqrt{2}}(|g\rangle + e^{i\phi}|e\rangle)$
$\Delta x(t) = \frac{\Delta E}{m_{\text{atom}}} t$
$N_{|g\rangle}/(N_{|g\rangle}+N_{|e\rangle})$
tunable phase ϕ
$\left.\frac{N_{|g\rangle}}{N_{|g\rangle}+N_{|e\rangle}}\right|_{\text{exp}}(\phi) = \frac{1}{2}(1 + V\cos(\phi + \Delta\phi))$

Quantum sensors

atom interferometers

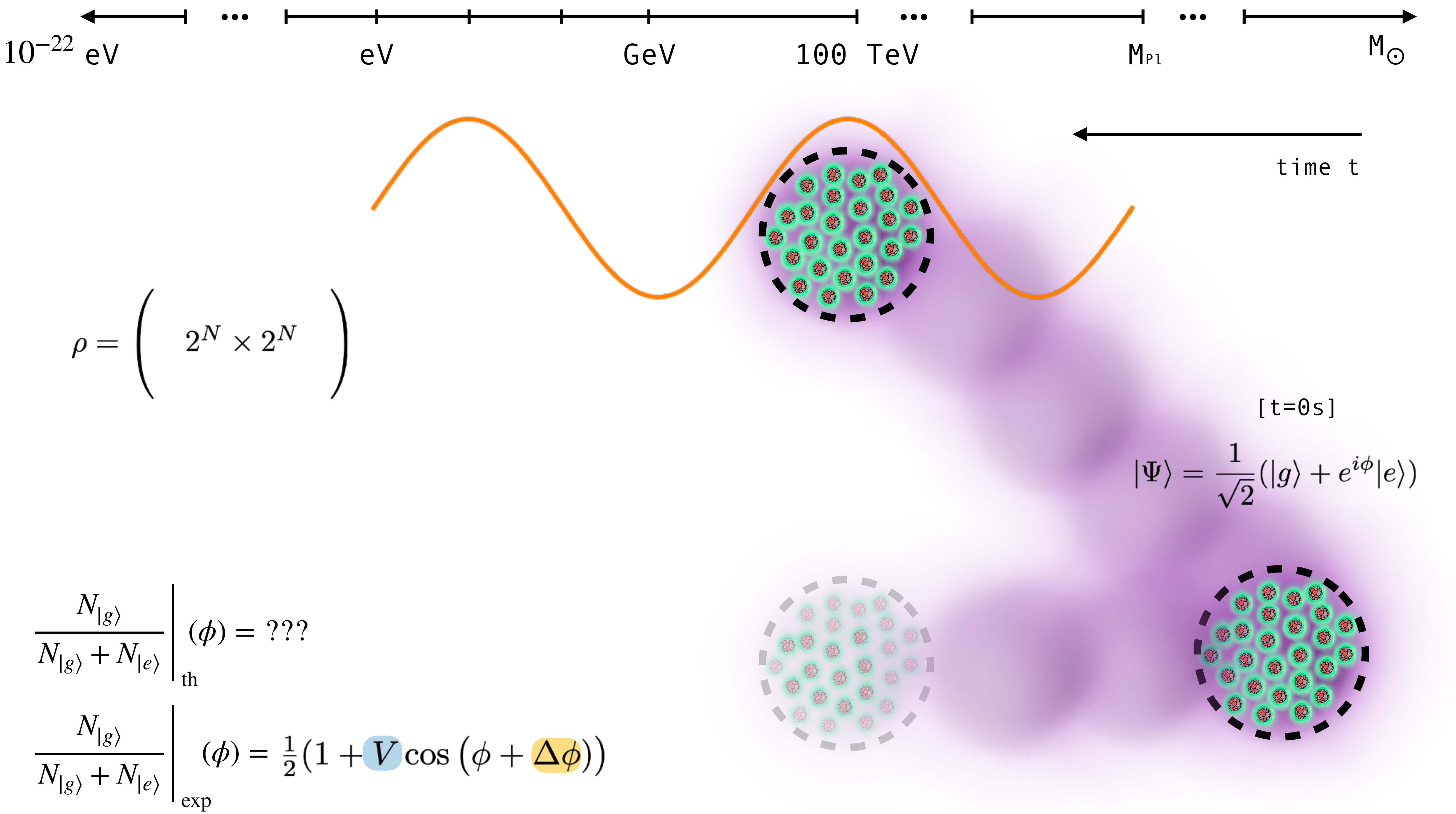


$$\left.\frac{N_{|g\rangle}}{N_{|g\rangle}+N_{|e\rangle}}\right|_{\text{th}}(\phi) = ???$$

$$\left.\frac{N_{|g\rangle}}{N_{|g\rangle}+N_{|e\rangle}}\right|_{\text{exp}}(\phi) = \frac{1}{2}(1 + V\cos(\phi + \Delta\phi))$$

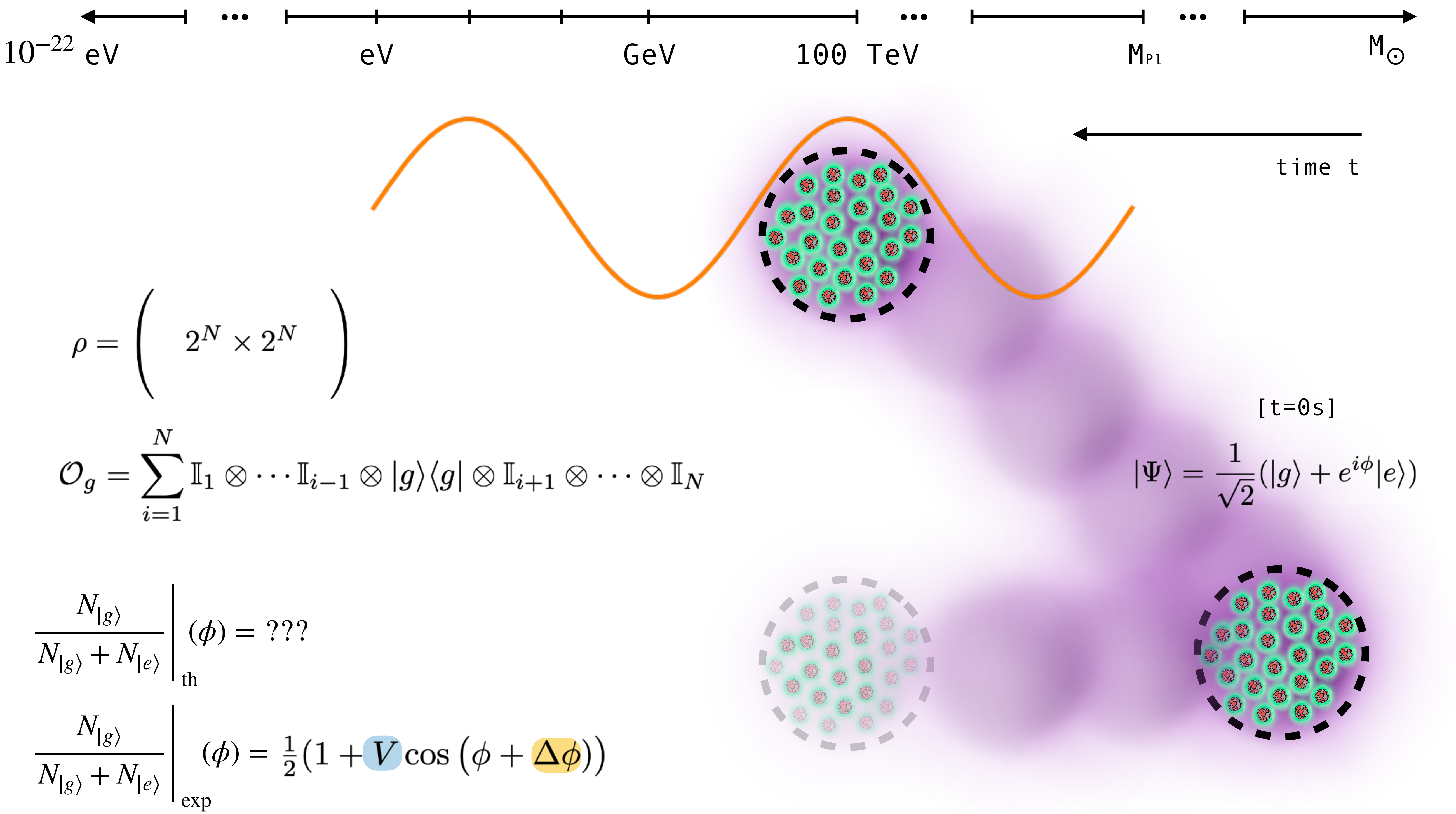
Quantum sensors

atom interferometers



Quantum sensors

atom interferometers



$$\rho = \begin{pmatrix} & 2^N \times 2^N & \end{pmatrix}$$

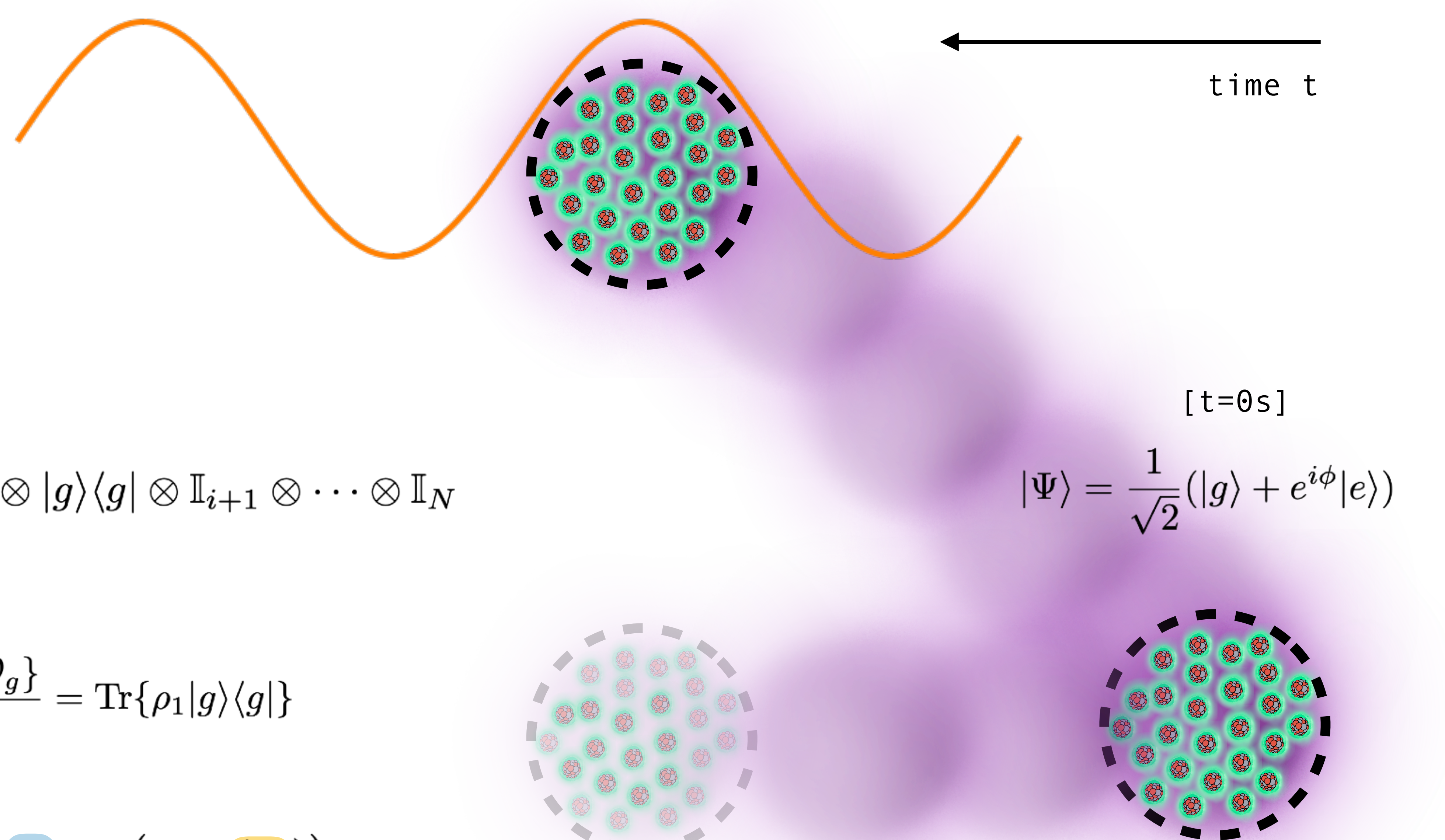
$$\mathcal{O}_g = \sum_{i=1}^{N} \mathbb{I}_1 \otimes \cdots \mathbb{I}_{i-1} \otimes |g\rangle\langle g| \otimes \mathbb{I}_{i+1} \otimes \cdots \otimes \mathbb{I}_N$$

$$\left.\frac{N_{|g\rangle}}{N_{|g\rangle} + N_{|e\rangle}}\right|_{\text{th}} (\phi) = ???$$

$$\left.\frac{N_{|g\rangle}}{N_{|g\rangle} + N_{|e\rangle}}\right|_{\text{exp}} (\phi) = \frac{1}{2}(1 + V \cos(\phi + \Delta\phi))$$

Quantum sensors

atom interferometers



$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|g\rangle + e^{i\phi}|e\rangle)$$

$$\rho = \begin{pmatrix} & 2^N \times 2^N & \end{pmatrix}$$

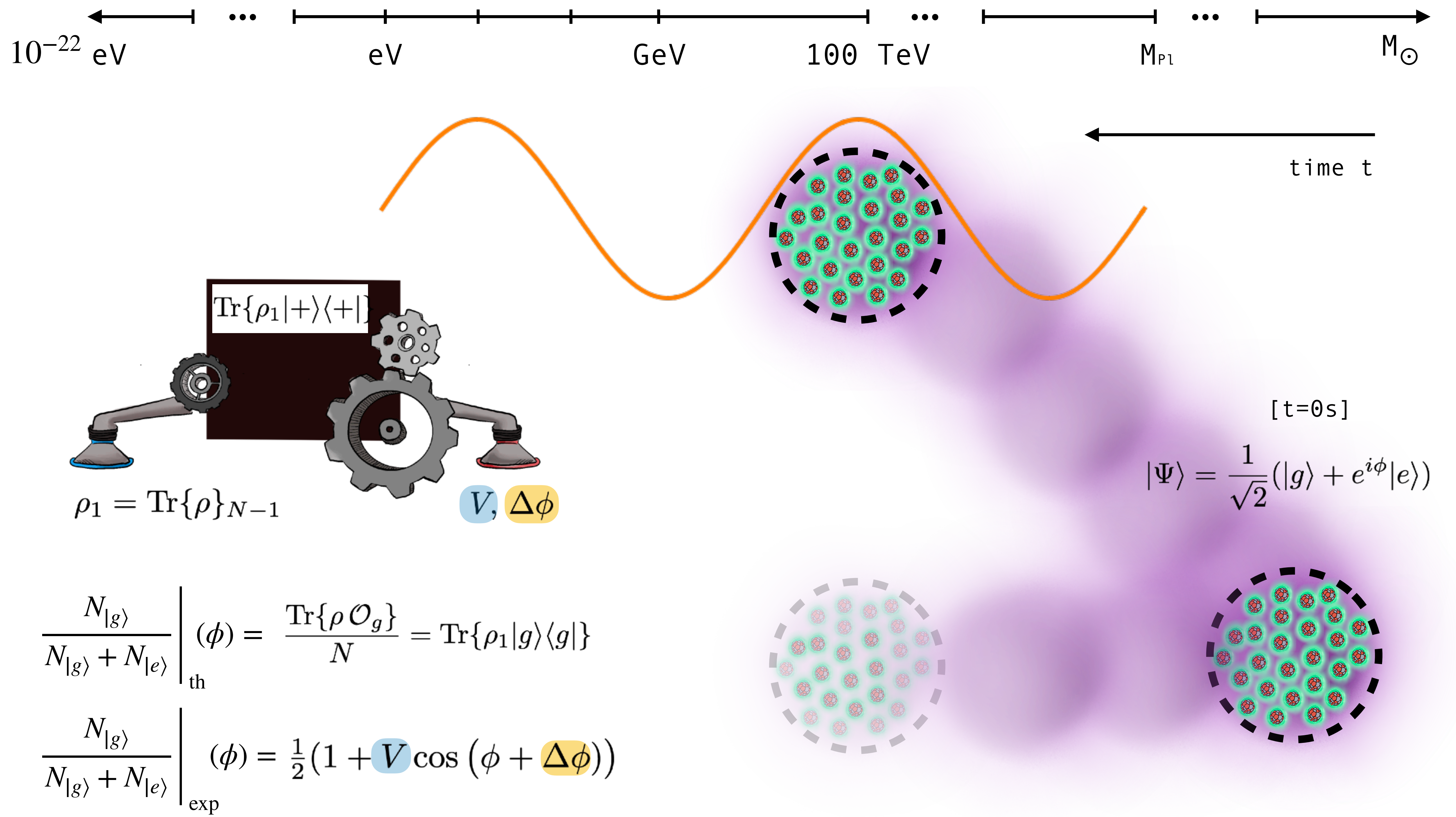
$$\mathcal{O}_g = \sum_{i=1}^{N} \mathbb{I}_1 \otimes \cdots \mathbb{I}_{i-1} \otimes |g\rangle\langle g| \otimes \mathbb{I}_{i+1} \otimes \cdots \otimes \mathbb{I}_N$$

$$\left.\frac{N_{|g\rangle}}{N_{|g\rangle} + N_{|e\rangle}}\right|_{\text{th}} (\phi) = \frac{\text{Tr}\{\rho\, \mathcal{O}_g\}}{N} = \text{Tr}\{\rho_1 |g\rangle\langle g|\}$$

$$\left.\frac{N_{|g\rangle}}{N_{|g\rangle} + N_{|e\rangle}}\right|_{\text{exp}} (\phi) = \frac{1}{2}(1 + V \cos{(\phi + \Delta\phi)})$$

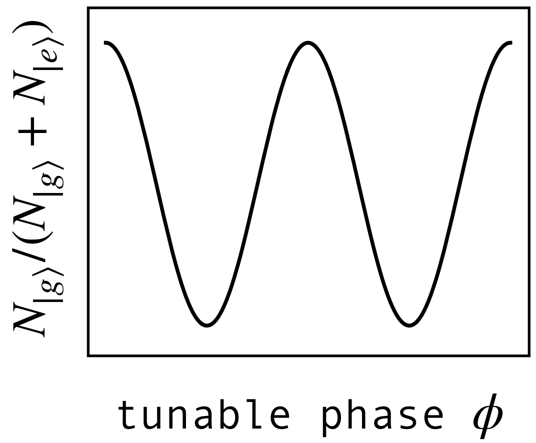
Quantum sensors

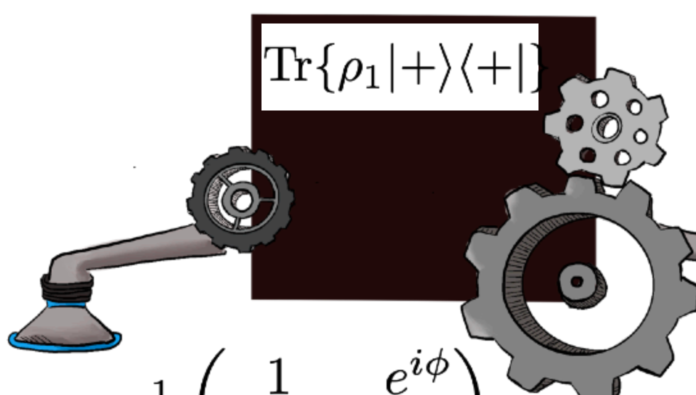
atom interferometers



Quantum sensors

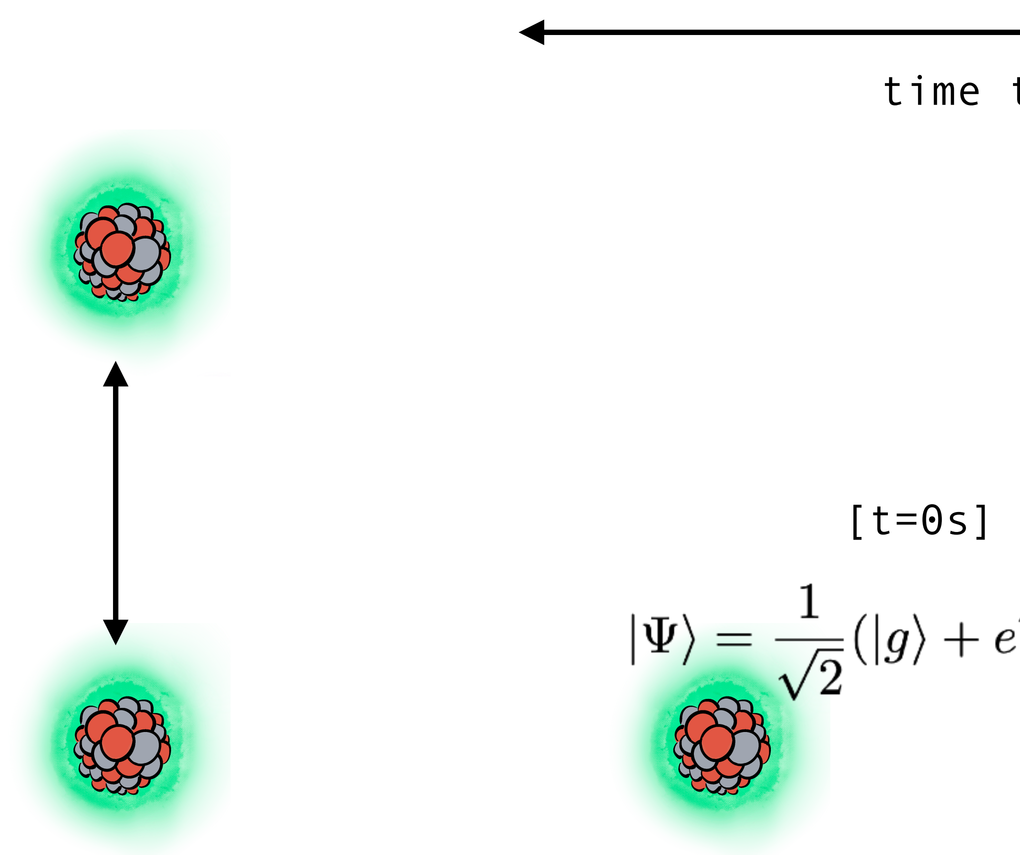
single atom interferometer





$$\rho_1 = \frac{1}{2}\begin{pmatrix} 1 & e^{i\phi} \\ e^{-i\phi} & 1 \end{pmatrix}$$

V, $\Delta\phi$



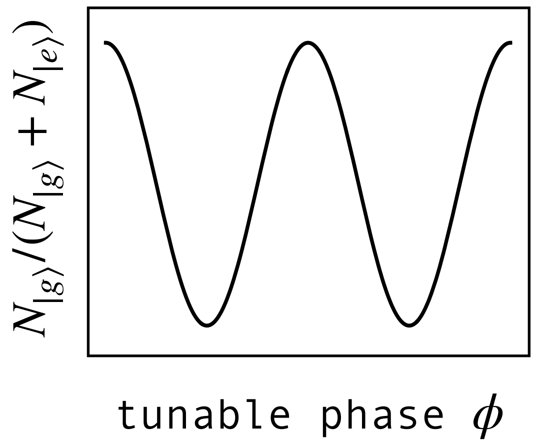
$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|g\rangle + e^{i\phi}|e\rangle)$$

$$\left.\frac{N_{|g\rangle}}{N_{|g\rangle}+N_{|e\rangle}}\right|_{\mathrm{th}}(\phi) = \frac{1}{2}(1+\cos\phi)$$

$$\left.\frac{N_{|g\rangle}}{N_{|g\rangle}+N_{|e\rangle}}\right|_{\mathrm{exp}}(\phi) = \frac{1}{2}(1+V\cos(\phi+\Delta\phi))$$

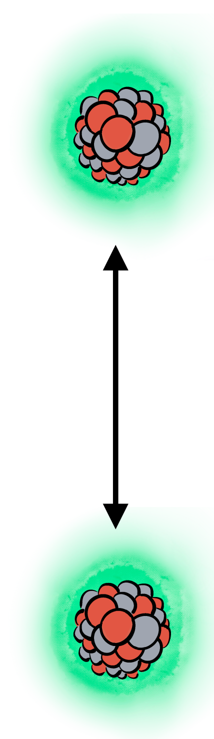
Quantum sensors

single atom interferometer



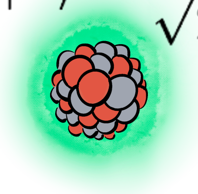
$\chi(\mathbf{k})$

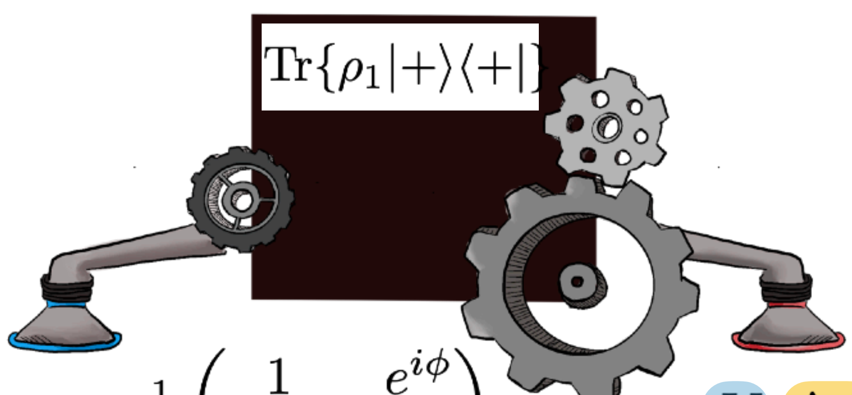
time t



[t=0s]

$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|g\rangle + e^{i\phi}|e\rangle)$$





$$\rho_1 = \frac{1}{2}\begin{pmatrix} 1 & e^{i\phi} \\ e^{-i\phi} & 1 \end{pmatrix}$$

V, $\Delta\phi$

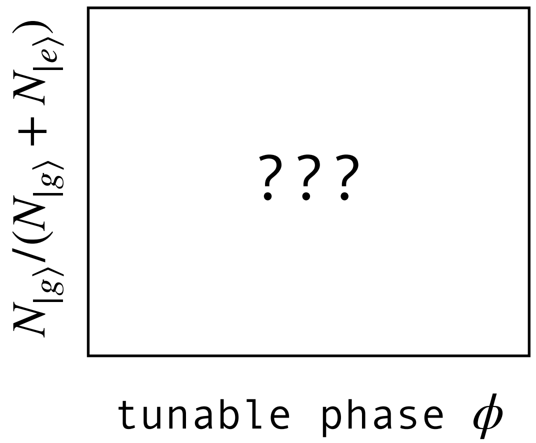
$$\left.\frac{N_{|g\rangle}}{N_{|g\rangle}+N_{|e\rangle}}\right|_{\mathrm{th}}(\phi) = \frac{1}{2}(1+\cos\phi)$$

$$\left.\frac{N_{|g\rangle}}{N_{|g\rangle}+N_{|e\rangle}}\right|_{\mathrm{exp}}(\phi) = \frac{1}{2}(1+V\cos(\phi+\Delta\phi))$$

Quantum sensors

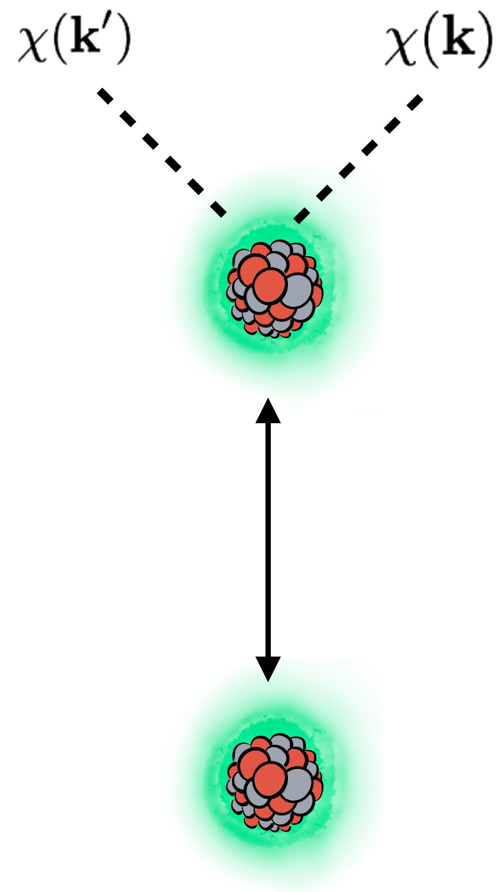
single atom interferometer

[Joss, Zeh, 1985]
[Gallis, Fleming, 1990]
[Hornberger, Sipe, 2003]



$$S\left(|\mathbf{x}\rangle \otimes |\mathbf{k}\rangle\right) = |\mathbf{x}\rangle \otimes S_{\{\mathbf{x}\}}|\mathbf{k}\rangle$$

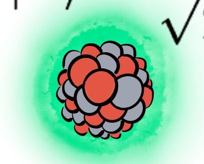
$$\rho'_A = \mathrm{Tr}_{\mathbf{k}}\rho'$$

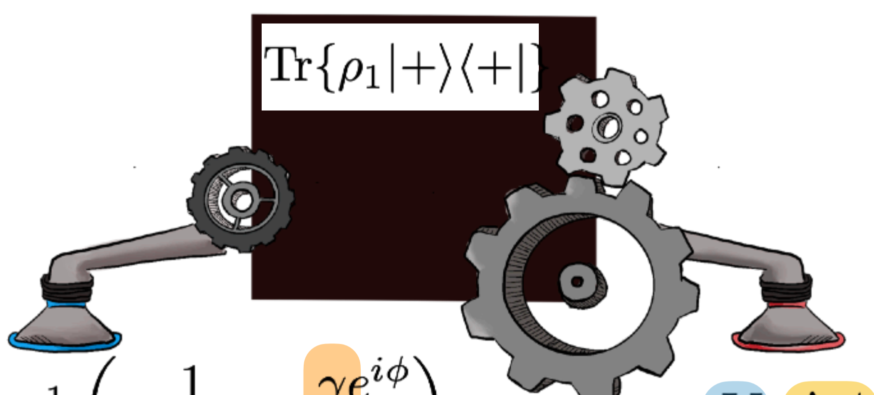


time t

[t=0s]

$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|g\rangle + e^{i\phi}|e\rangle)$$





$$\rho_1 = \frac{1}{2}\begin{pmatrix} 1 & \gamma e^{i\phi} \\ \gamma^* e^{-i\phi} & 1 \end{pmatrix}$$

$$\left.\frac{N_{|g\rangle}}{N_{|g\rangle}+N_{|e\rangle}}\right|_{\mathrm{th}}(\phi) = \;???$$

$$\left.\frac{N_{|g\rangle}}{N_{|g\rangle}+N_{|e\rangle}}\right|_{\mathrm{exp}}(\phi) = \frac{1}{2}(1 + V\cos\left(\phi + \Delta\phi\right))$$

$$\rho' = S\rho S^\dagger = (\mathbb{I}+T)\rho(\mathbb{I}+T)^\dagger$$

$$\Rightarrow \Delta\rho = \frac{i}{2}[T+T^\dagger,\rho] - \frac{1}{2}\{T^\dagger T,\rho\} + T\rho T^\dagger$$

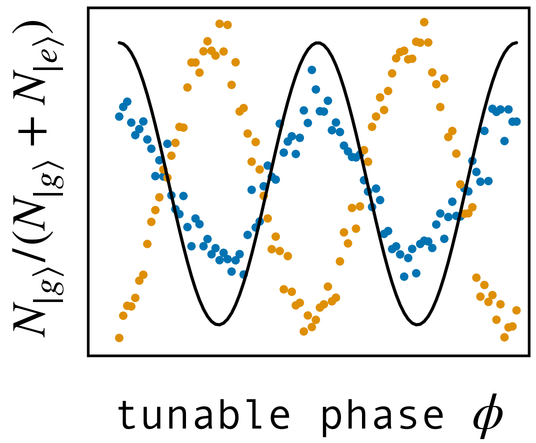
Quantum sensors

single atom interferometer

[Joss, Zeh, 1985]

[Gallis, Fleming, 1990]

[Hornberger, Sipe, 2003]



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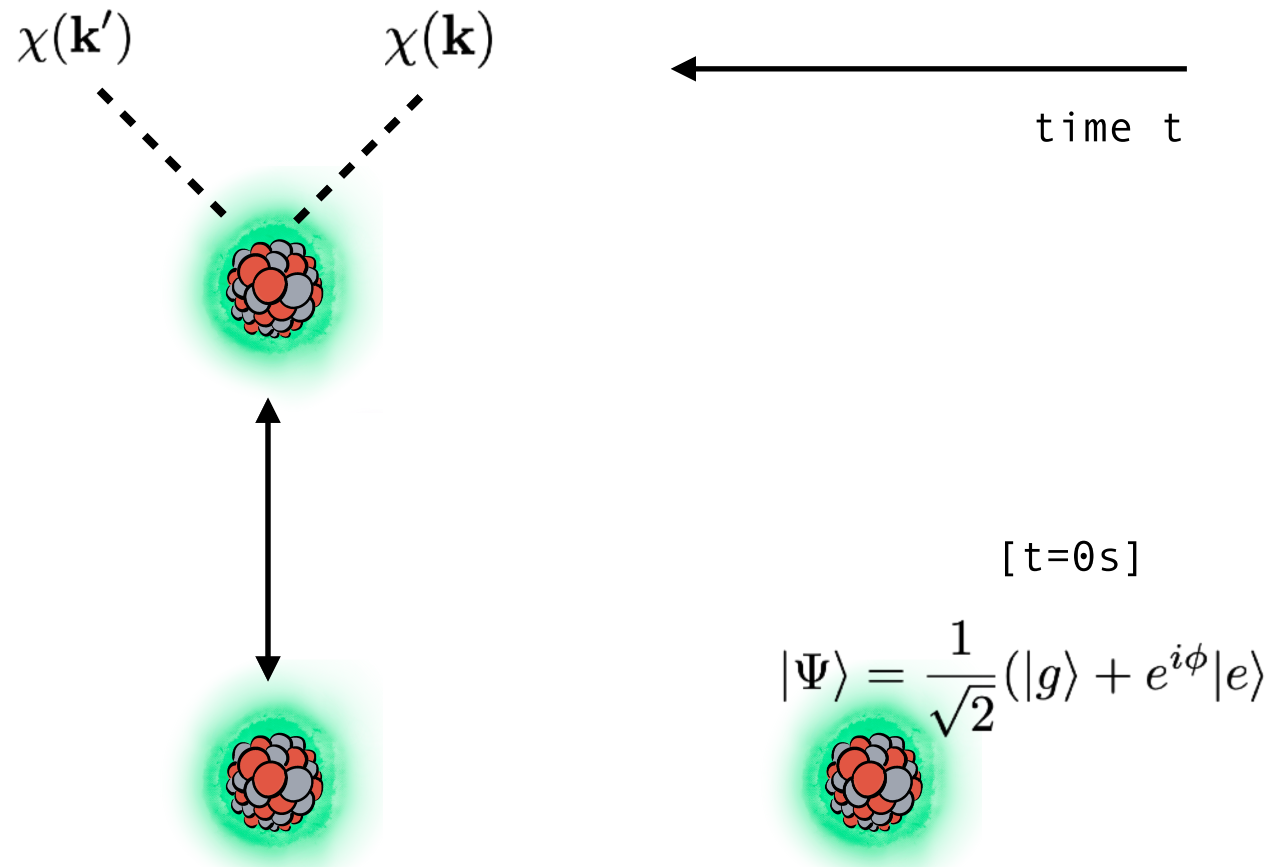

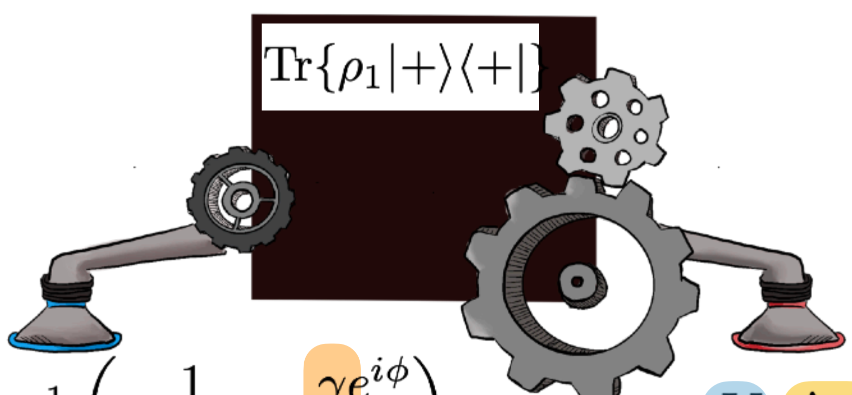

$$\rho_1 = \frac{1}{2}\begin{pmatrix} 1 & \gamma e^{i\phi} \\ \gamma^* e^{-i\phi} & 1 \end{pmatrix}$$

V, $\Delta\phi$

$$\left.\frac{N_{|g\rangle}}{N_{|g\rangle}+N_{|e\rangle}}\right|_{\mathrm{th}}(\phi) = \frac{1}{2}\left[1 + e^{-\int_{\mathbf{q},t} R(\mathbf{q})(1-\cos(\mathbf{q}\cdot\boldsymbol{\Delta}\mathbf{x}))}\cos\left(\phi + \int_{\mathbf{q},t} R(\mathbf{q})\sin(\mathbf{q}\cdot\boldsymbol{\Delta}\mathbf{x})\right)\right]$$

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Quantum sensors

single atom interferometer

[Joss, Zeh, 1985]

[Gallis, Fleming, 1990]

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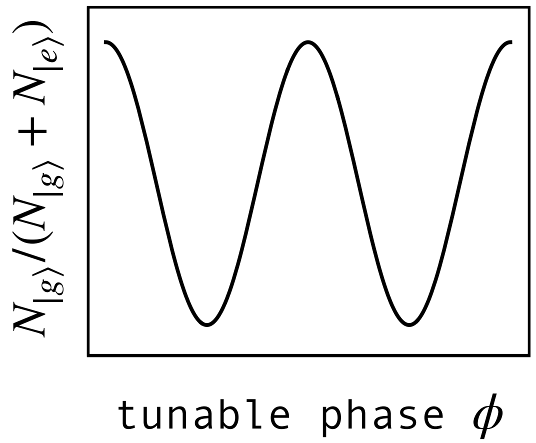

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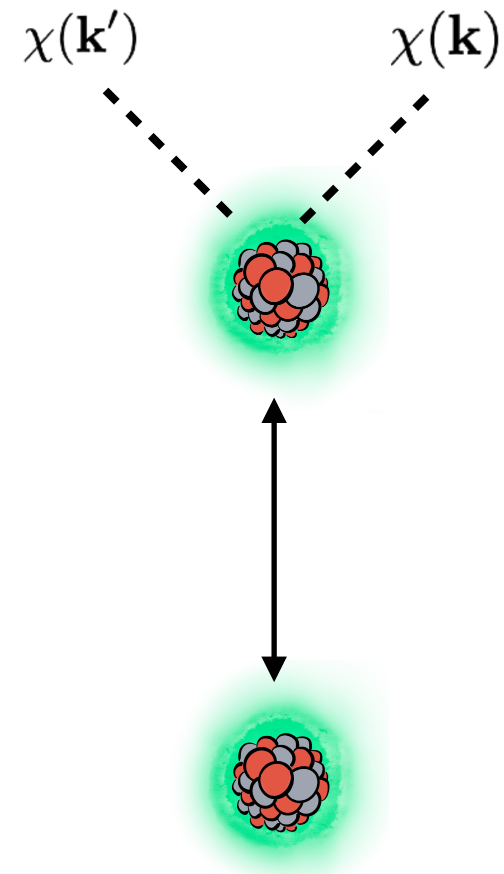
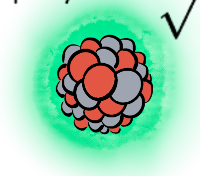
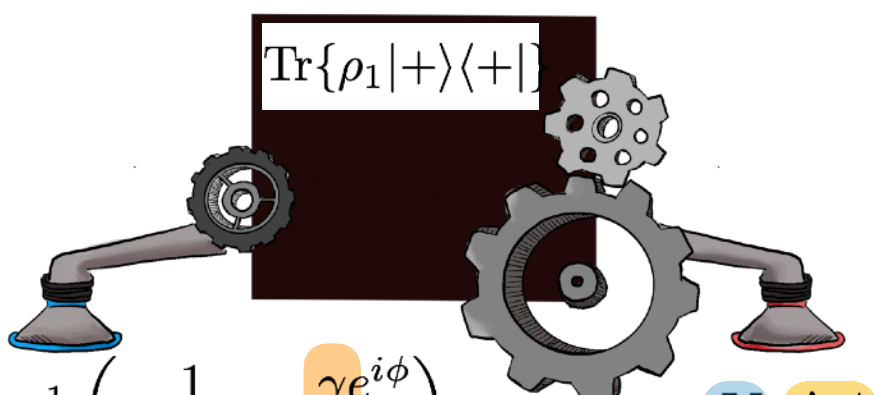


time t

[t=0s]

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left(|g\rangle + e^{i\phi}|e\rangle\right)$$





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1 $\Gamma \to 0 \quad \Rightarrow V = 1,\ \Delta\phi = 0$

Quantum sensors

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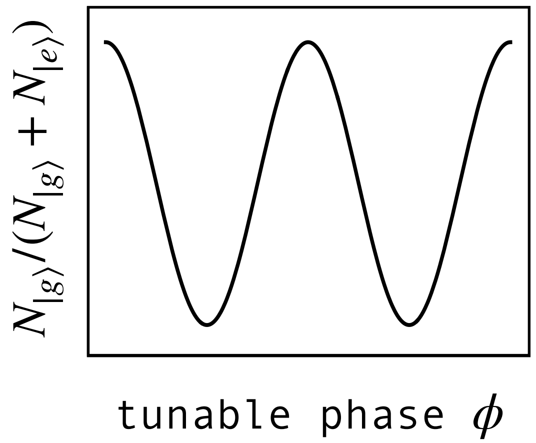

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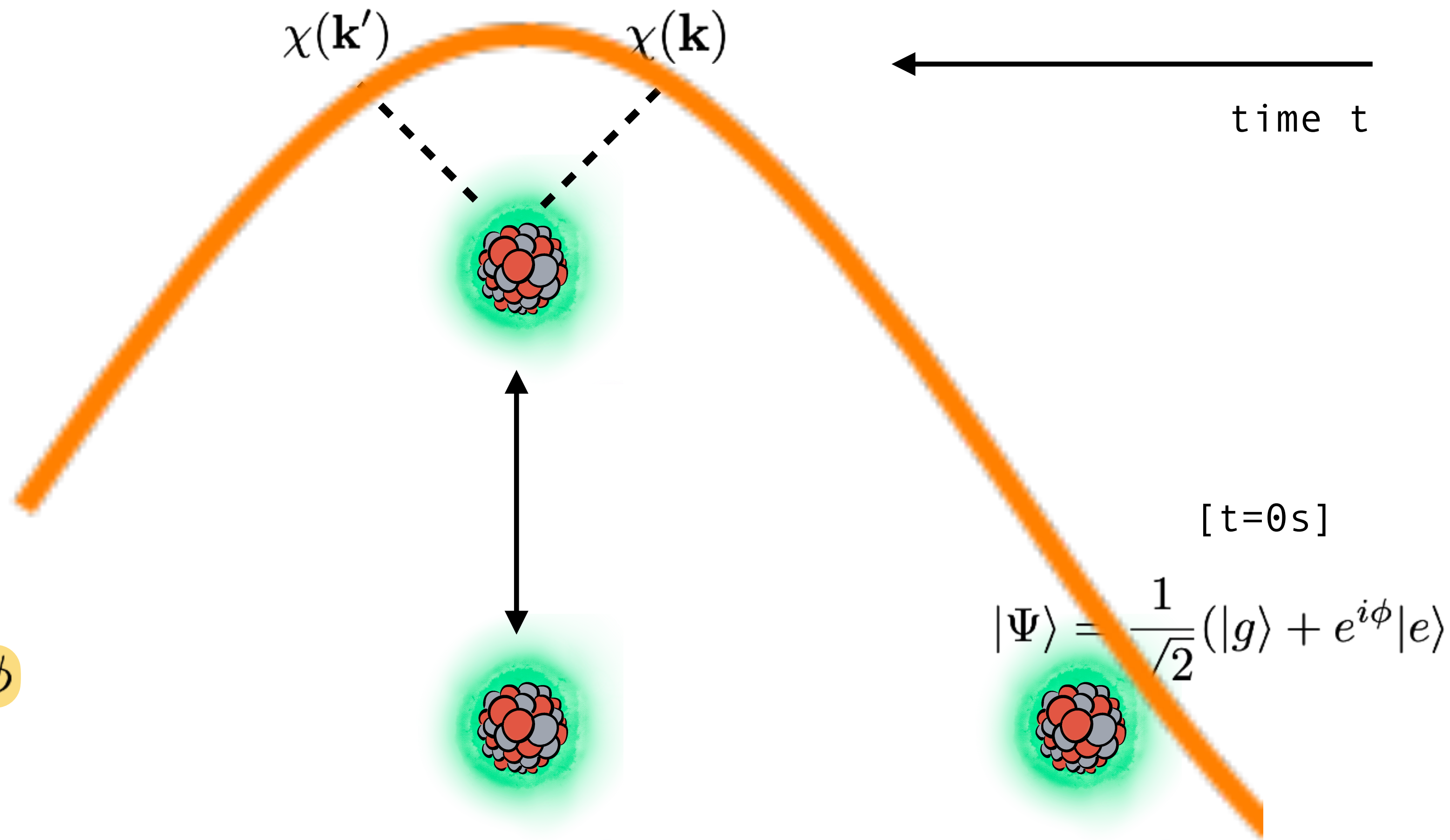

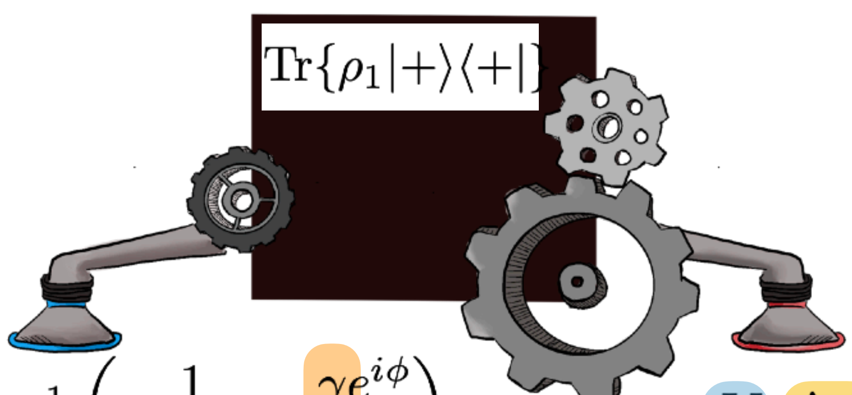

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2. $\Gamma \neq 0,\ q \ll 1/\Delta x \quad \Rightarrow V = 1,\ \Delta\phi = 0$

Quantum sensors

single atom interferometer

[Joss, Zeh, 1985]

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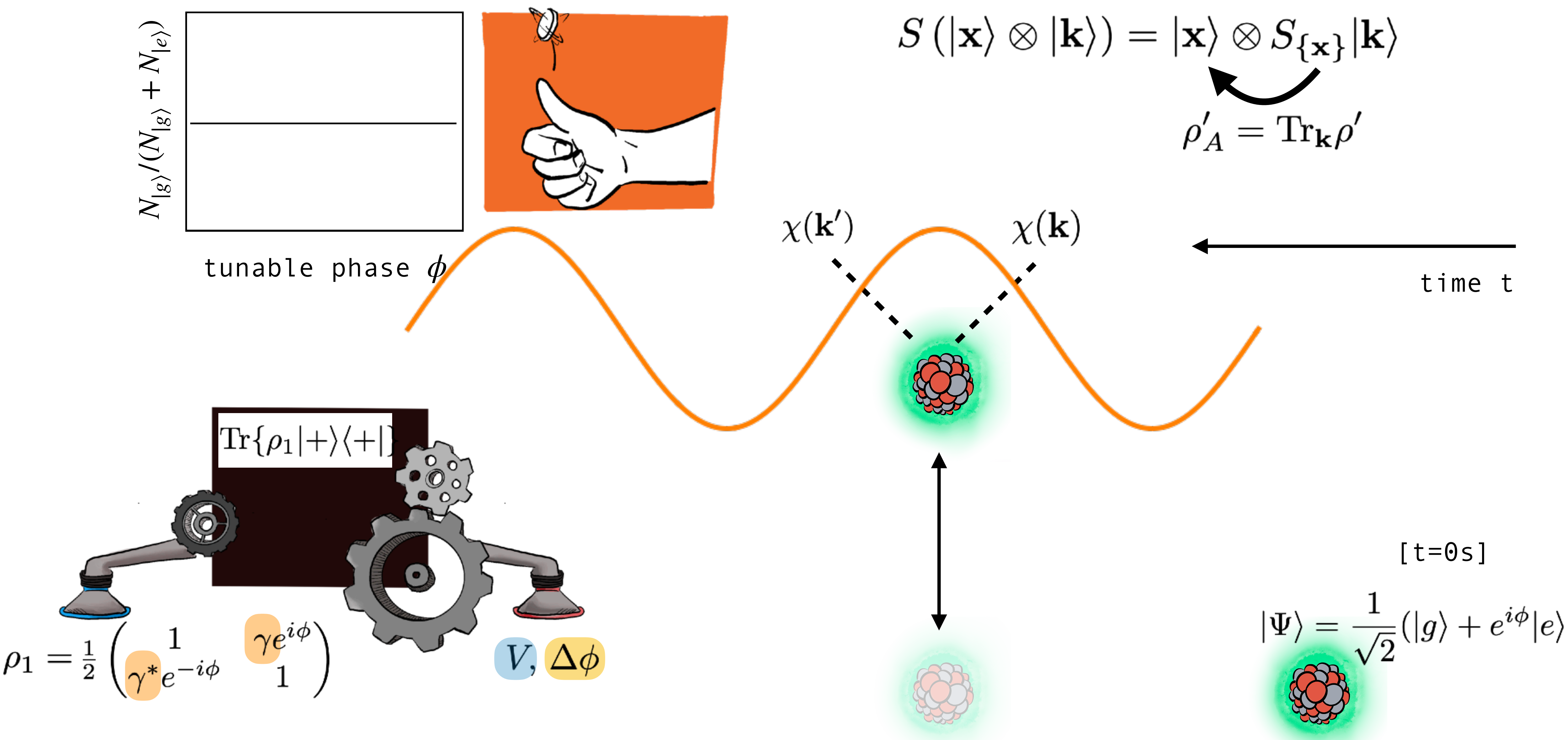

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Quantum sensors

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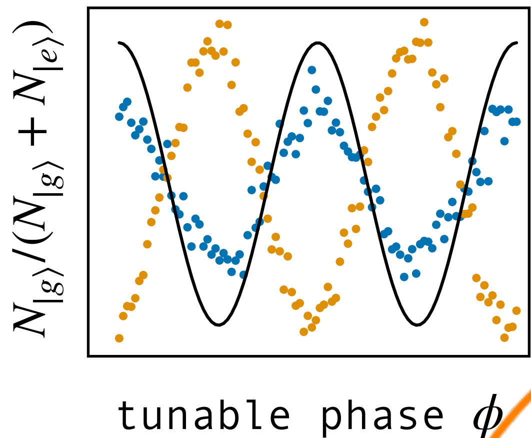

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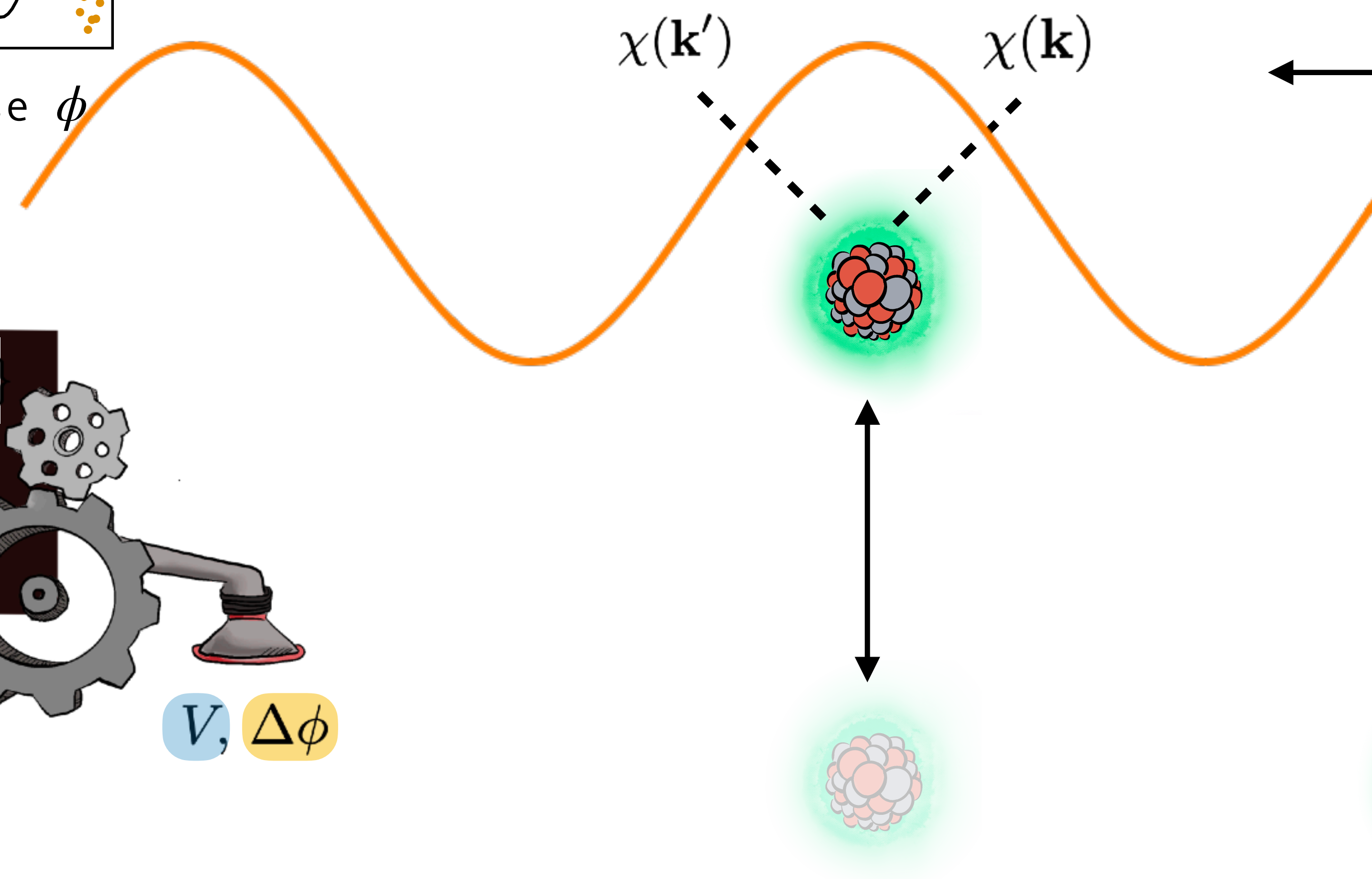

[t=0s]

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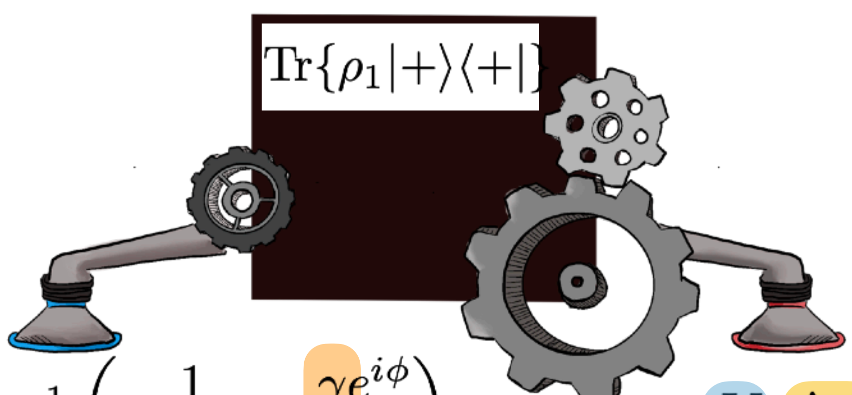

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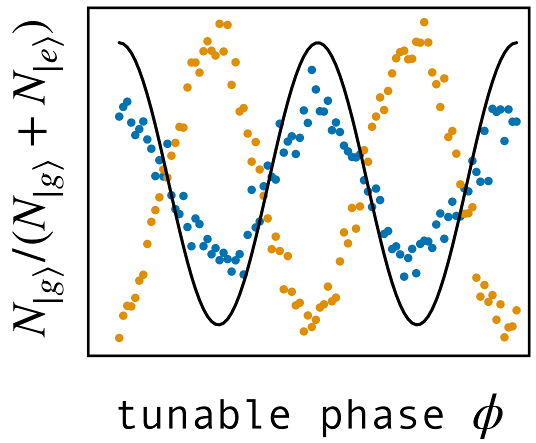
Quantum sensors

matter interferometer

[Riedel, 2012]

[Riedel, Yavin, 2016]



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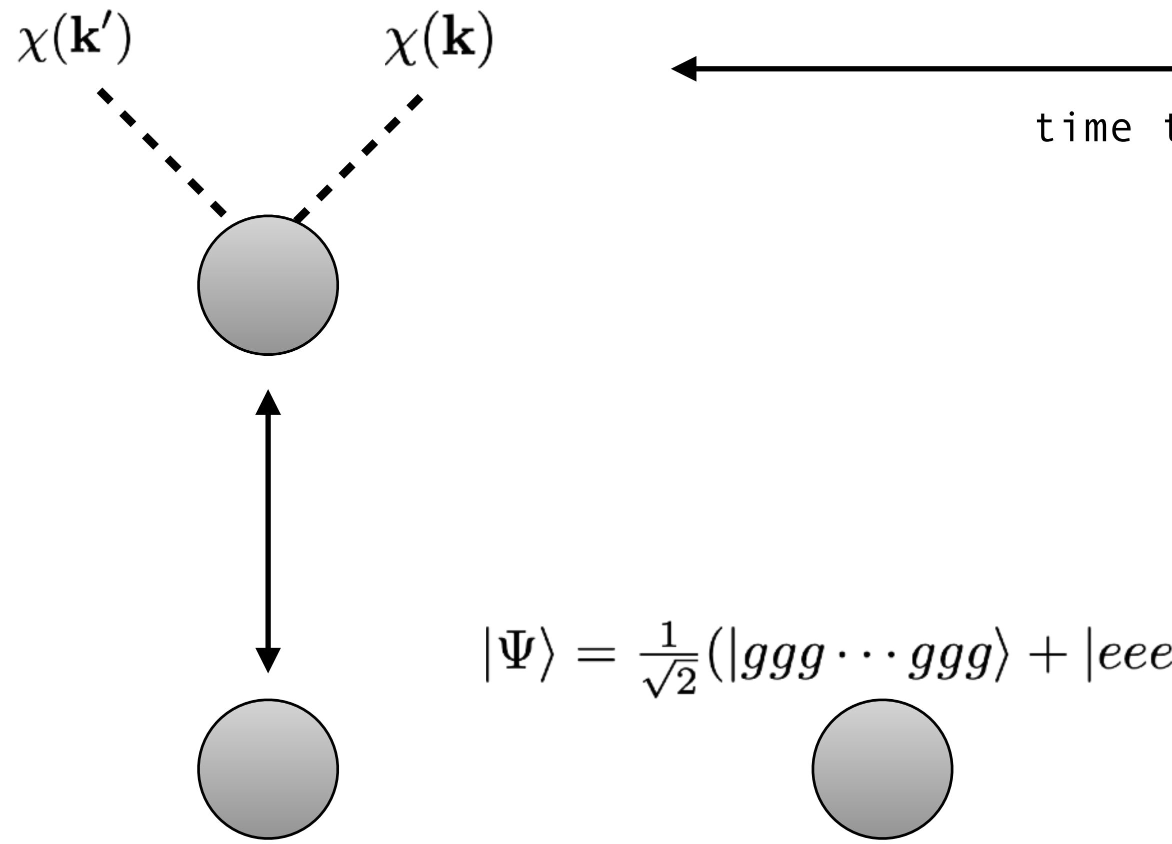
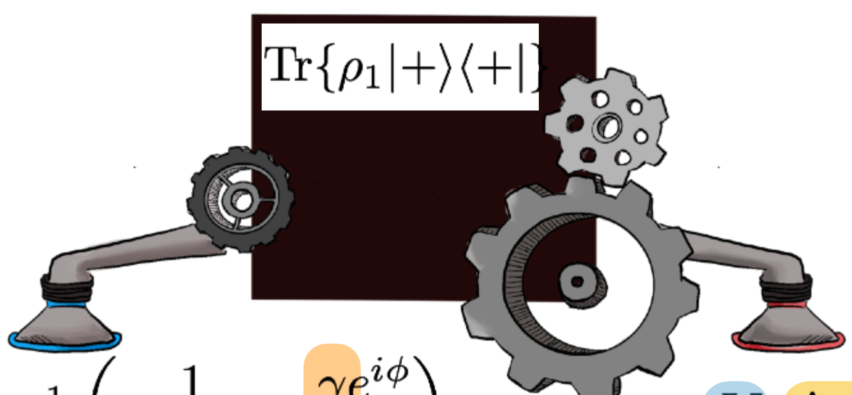


$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left(|ggg\cdots ggg\rangle + |eee\cdots eee\rangle\right)$$



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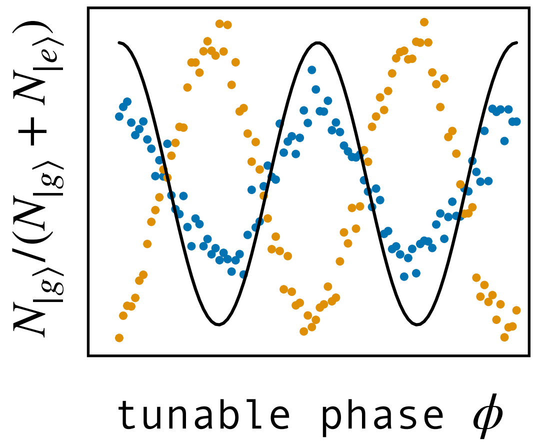
Quantum sensors

atom interferometers

[Badurina, CM, Plestid, 2024]



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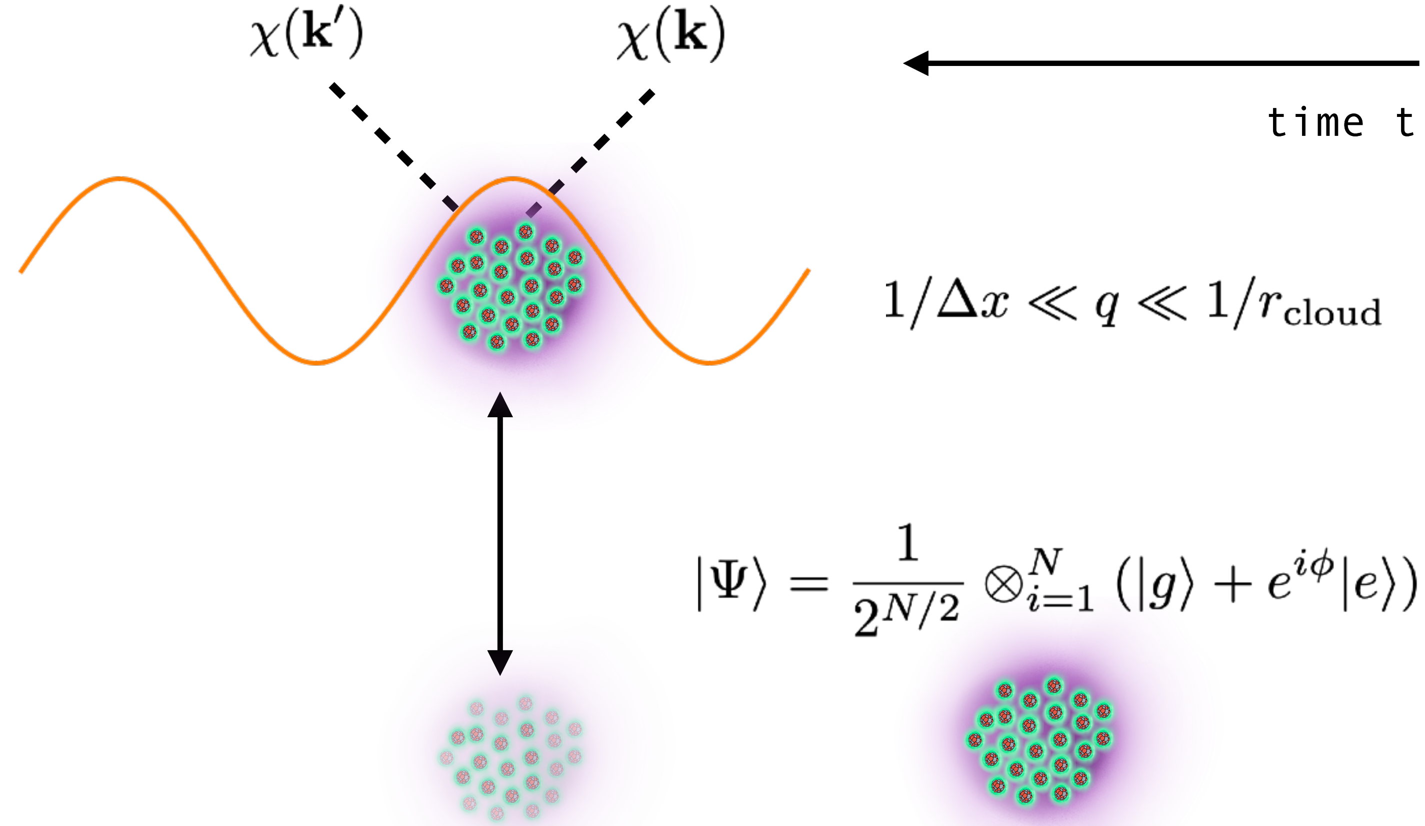

$$1/\Delta x\ll q\ll 1/r_{\rm cloud}$$

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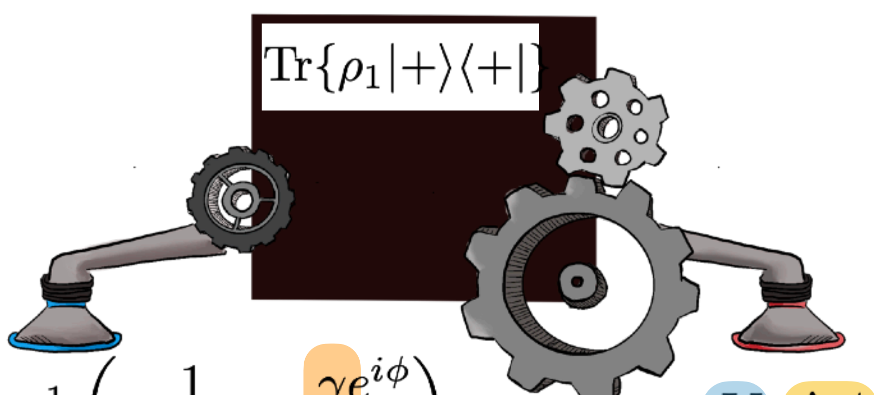

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Quantum sensors

atom interferometers

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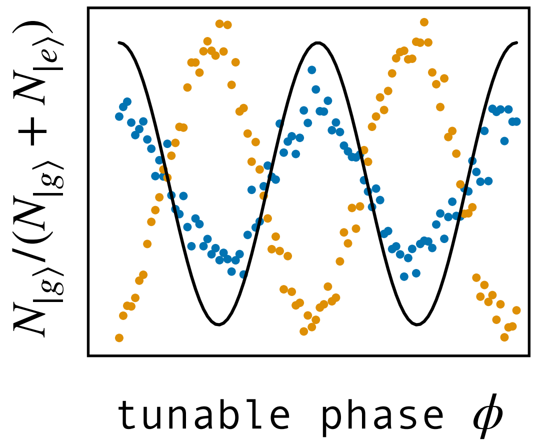

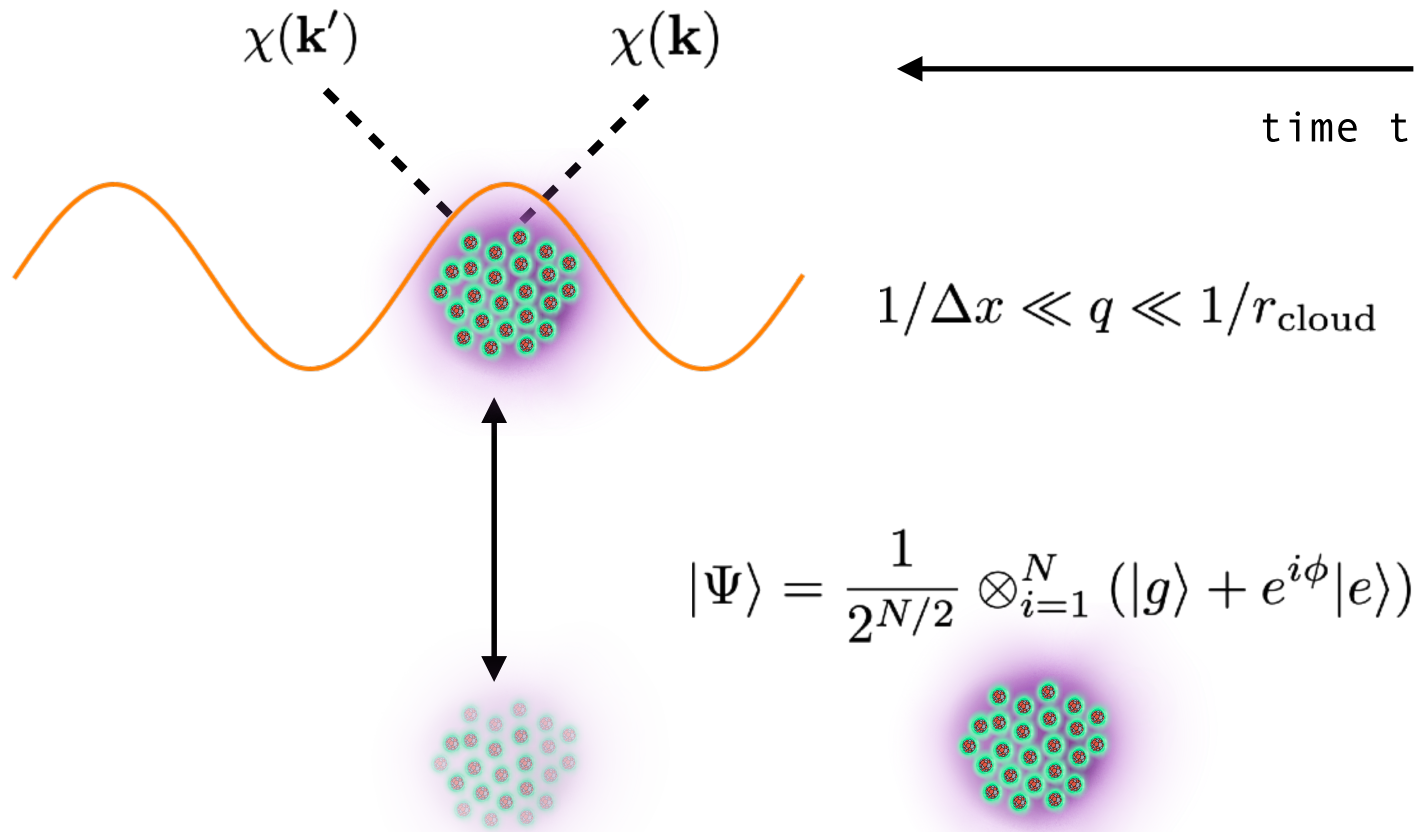

$$1/\Delta x \ll q \ll 1/r_{\mathrm{cloud}}$$

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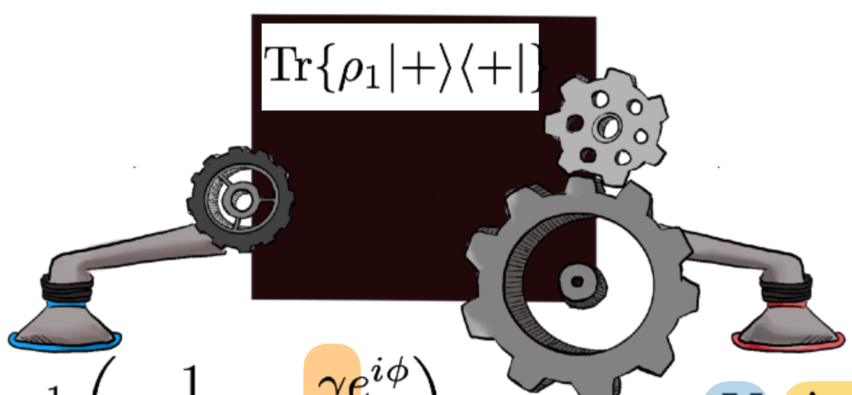

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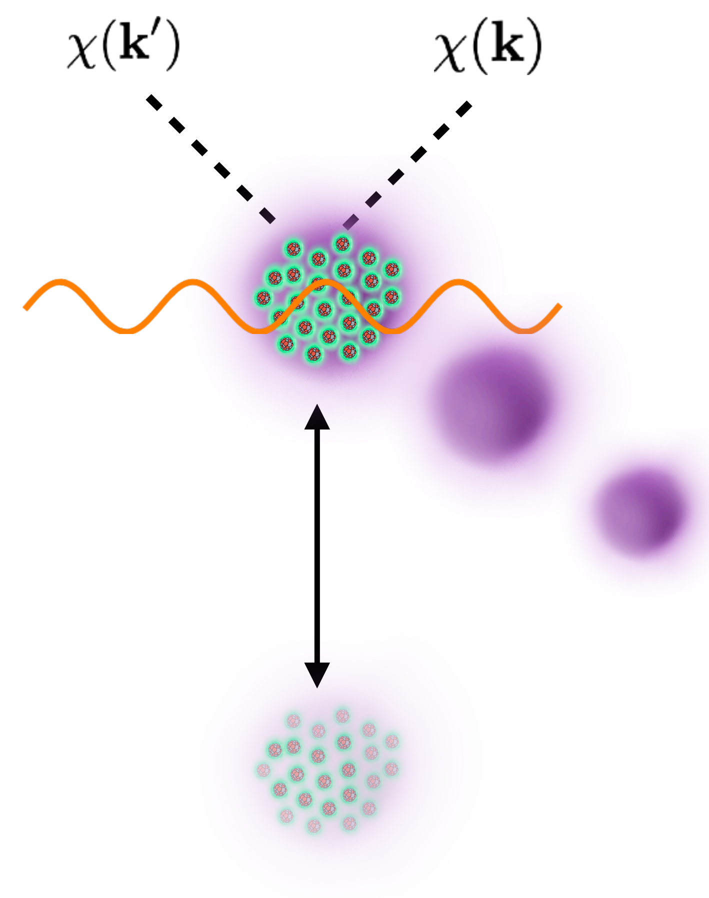
DM constraints [Du, Pardo, CM, Wang, Zurek 2022]

Backgrounds [Du, Pardo, CM, Wang, Zurek 2023]

Other observables [CM, Plestid, in preparation]

Quantum sensors

atom interferometers



Extended formalism

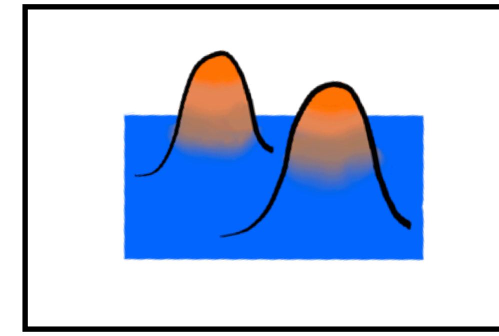
- ✓ cloud structure (∀q)
- ✓ cloud spreading (T effects)
- squeezing

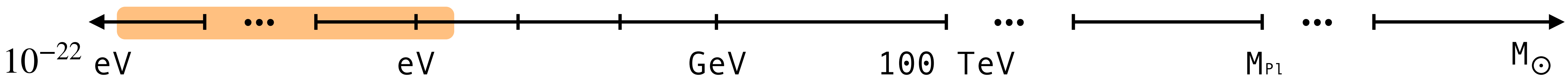
Testing @ the lab (SM physics)

- ✓ optimal experimental setup
- ✓ optimal background source

[CM, Plestid, 2508.XXXXX]

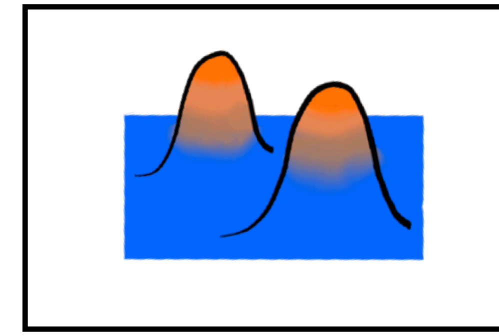
Quantum sensors

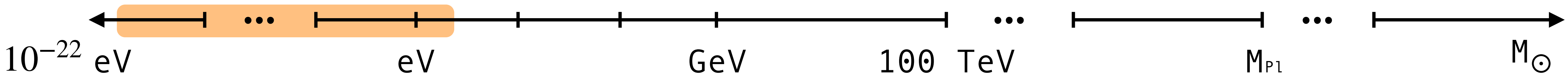


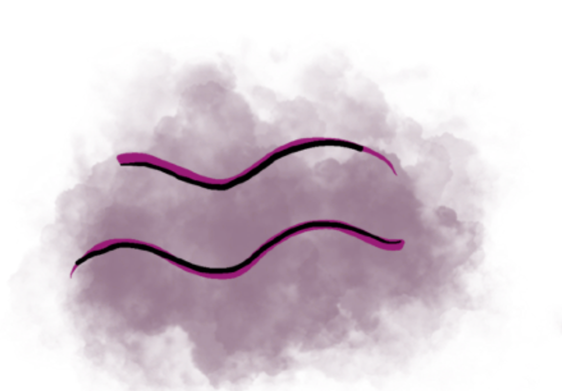


e.g. scalar $\mathcal{L} \supset g_{\phi\gamma}\ \phi\ FF + g_{\phi G}\ \phi\ GG - g_f\ \phi\ \bar{f} f + \mathrm{h.c.}$

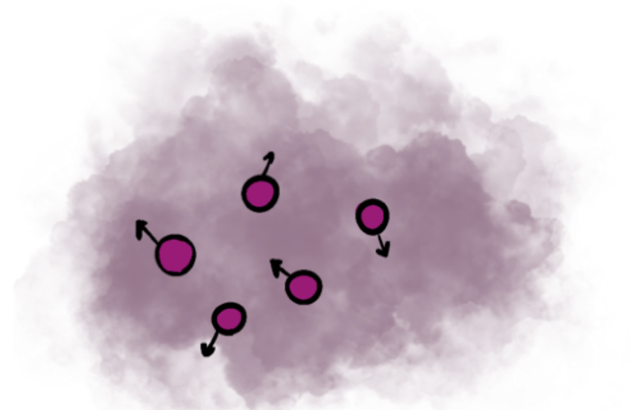
Quantum sensors







if d < $\lambda_{\rm dB}$



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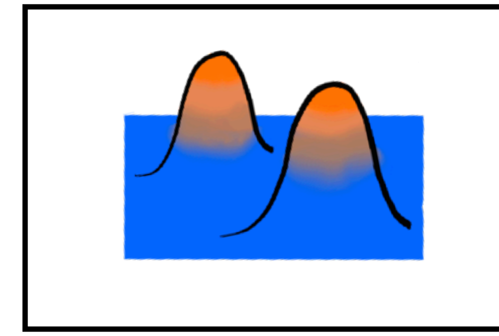
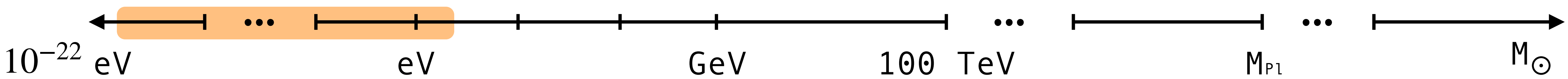
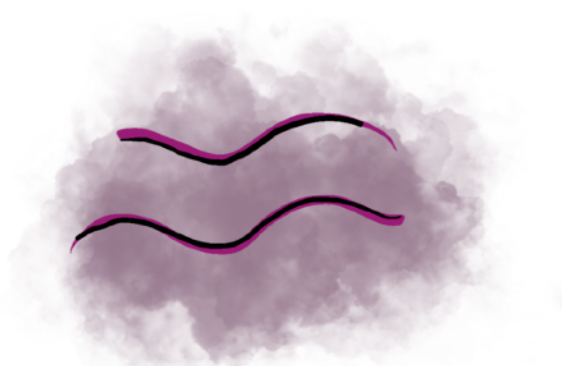
$$\longrightarrow \quad C_{\rm SM}(t) = C_{\rm SM} + \#\langle\phi\rangle$$

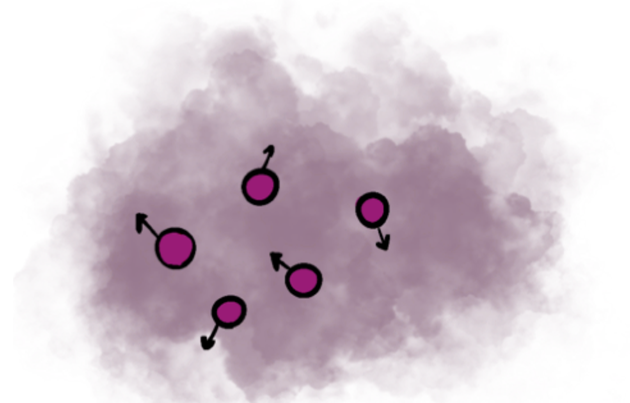
Quantum sensors





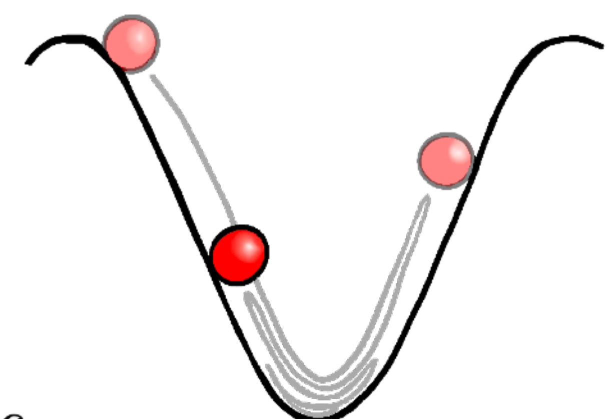


if d < λ_{dB}



if d > λ_{dB}

$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + m_\phi^2 \phi^2$$



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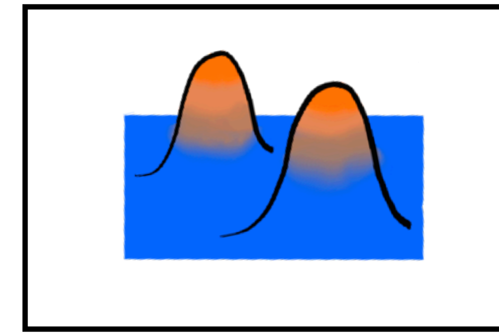
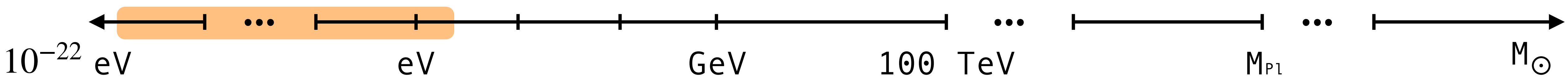
$$\longrightarrow \quad C_{\rm SM}(t) = C_{\rm SM} + \#\phi_0 \cos(m_\phi t)$$

$C_{\rm SM}(t)$ enter in atomic energy splittings! ⇒ precision physics @ low energies

Quantum sensors

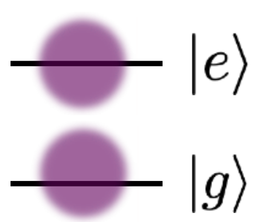
accelerometers





e.g. atomic clocks

$$\Delta E = f[C_{\rm SM}(t)]$$



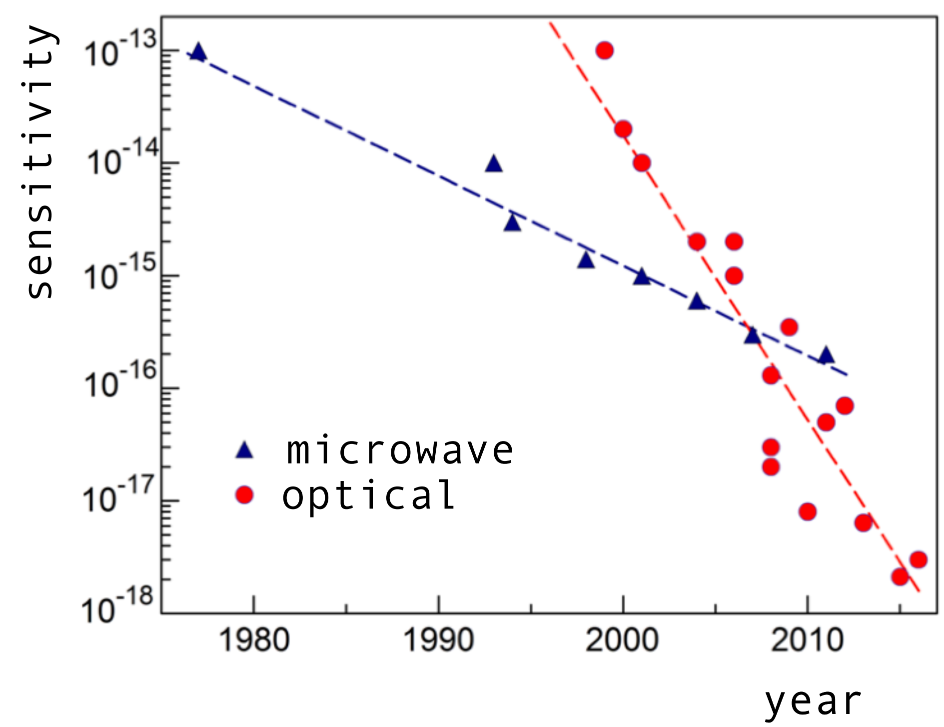
$|g\rangle$ state preparation

$\downarrow$

$$\frac{1}{\sqrt{2}}(|g\rangle + |e\rangle)$$

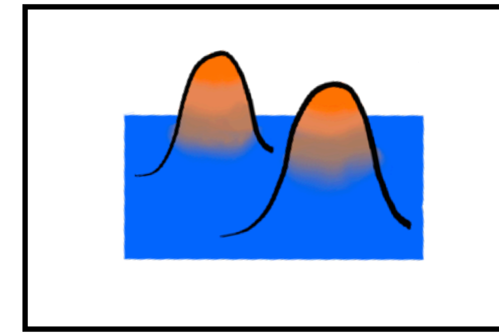
$\downarrow$ let system evolve

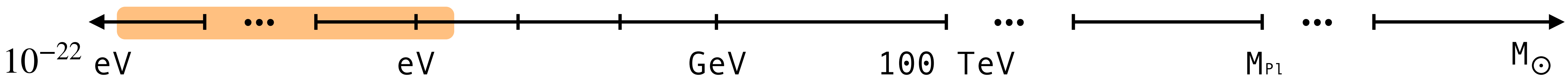
$$\frac{1}{\sqrt{2}}(|g\rangle + e^{i\Delta E t}|e\rangle)$$



Quantum sensors

accelerometers

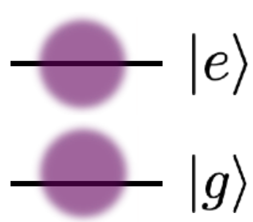


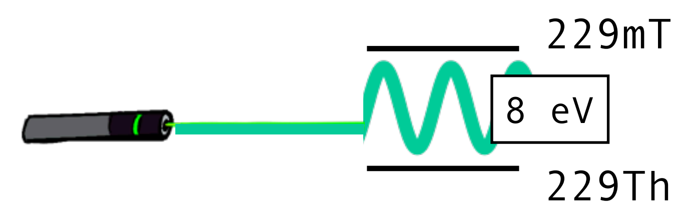


e.g. atomic clocks

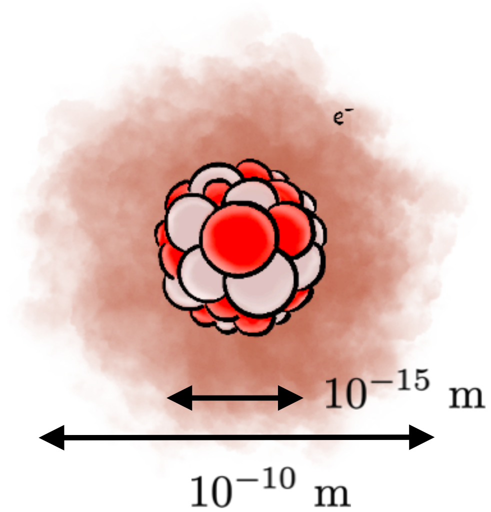
nuclear clocks

$$\Delta E = f[C_{\rm SM}(t)]$$





$$\omega_{\rm Th} = \omega_{\rm nuc} - \omega_{\rm EM} \sim 8 \text{ eV} \ll \text{MeV}$$



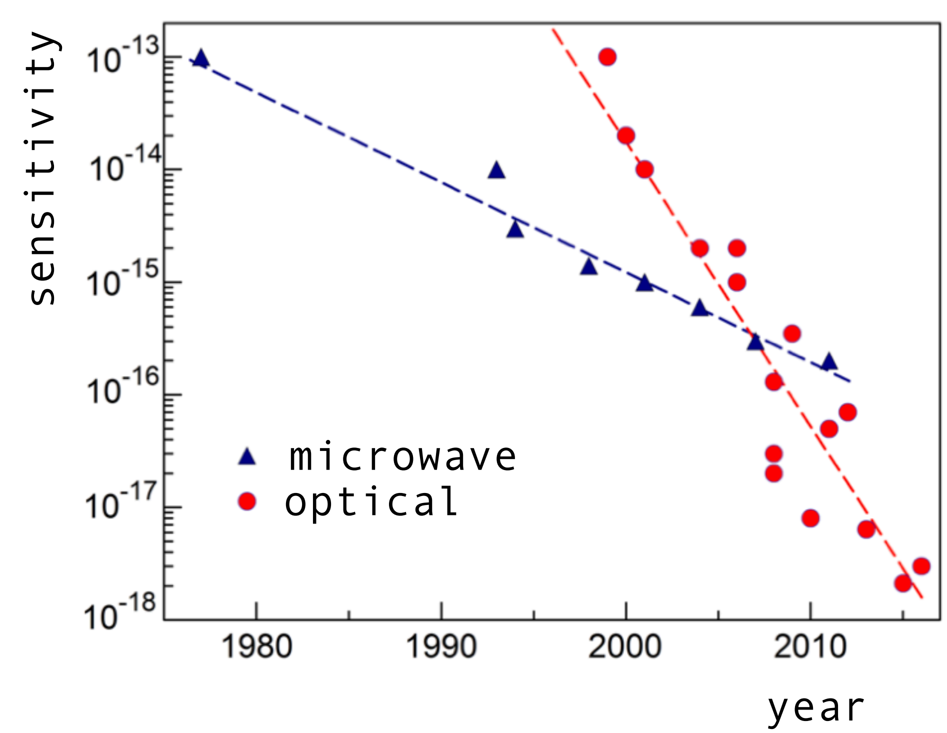
$|g\rangle$ state preparation

$\downarrow$

$\frac{1}{\sqrt{2}}(|g\rangle + |e\rangle)$

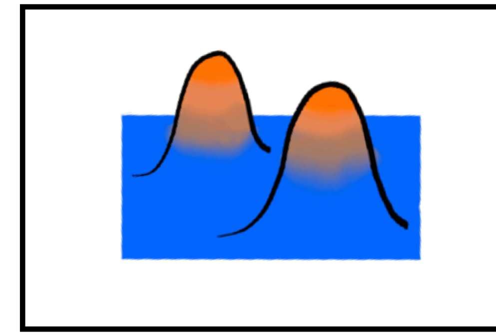
$\downarrow$ let system evolve

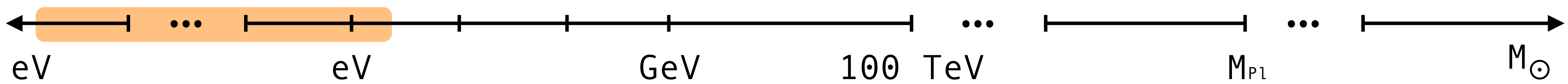
$\frac{1}{\sqrt{2}}(|g\rangle + e^{i\Delta E t}|e\rangle)$



Quantum sensors

accelerometers

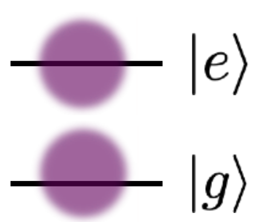




e.g. atomic clocks

nuclear clocks

$\Delta E = f[C_{\rm SM}(t)]$



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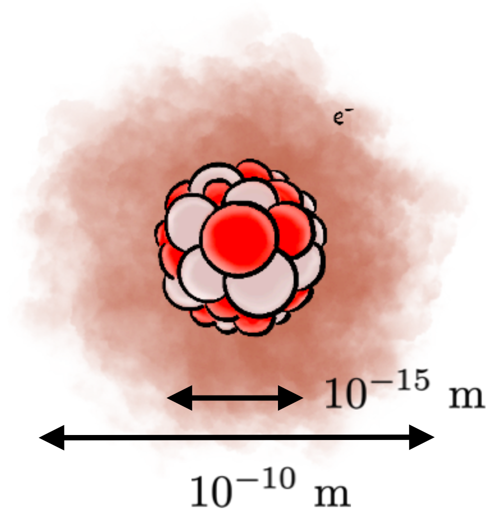

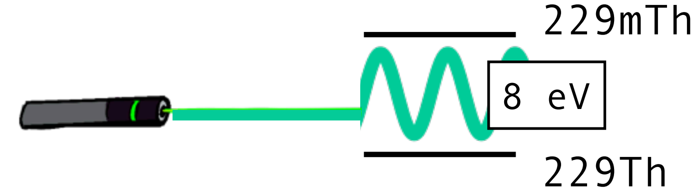

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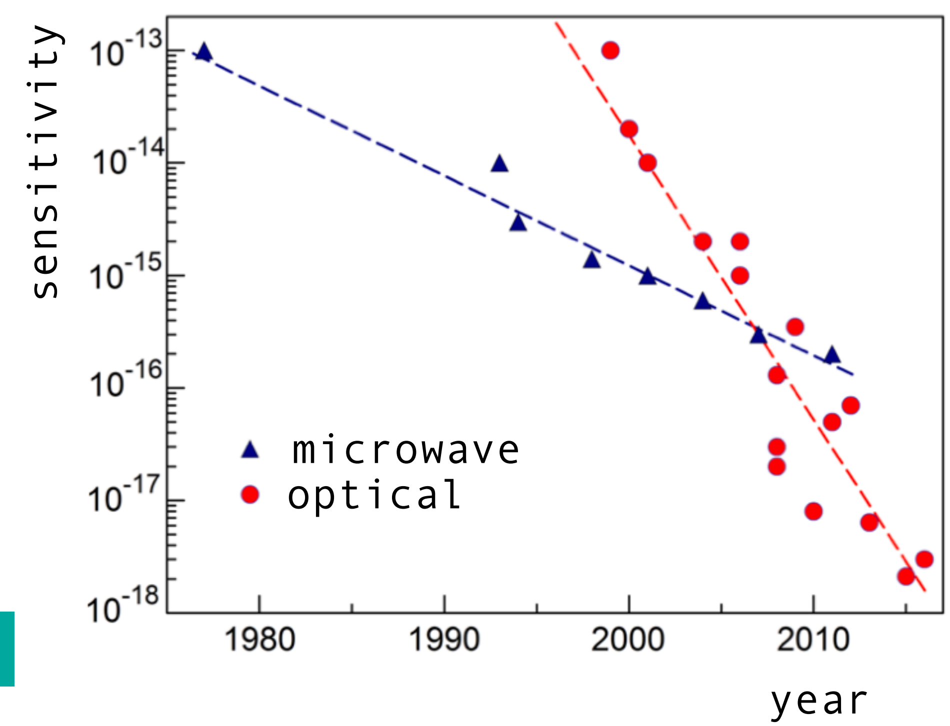
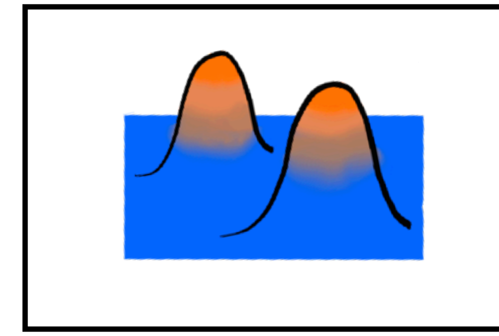
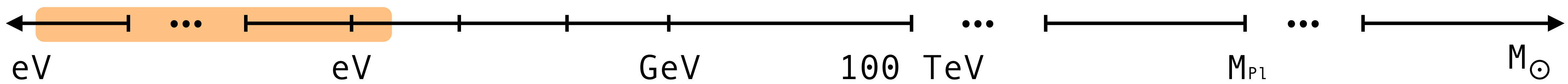


[Jack Shergold today]

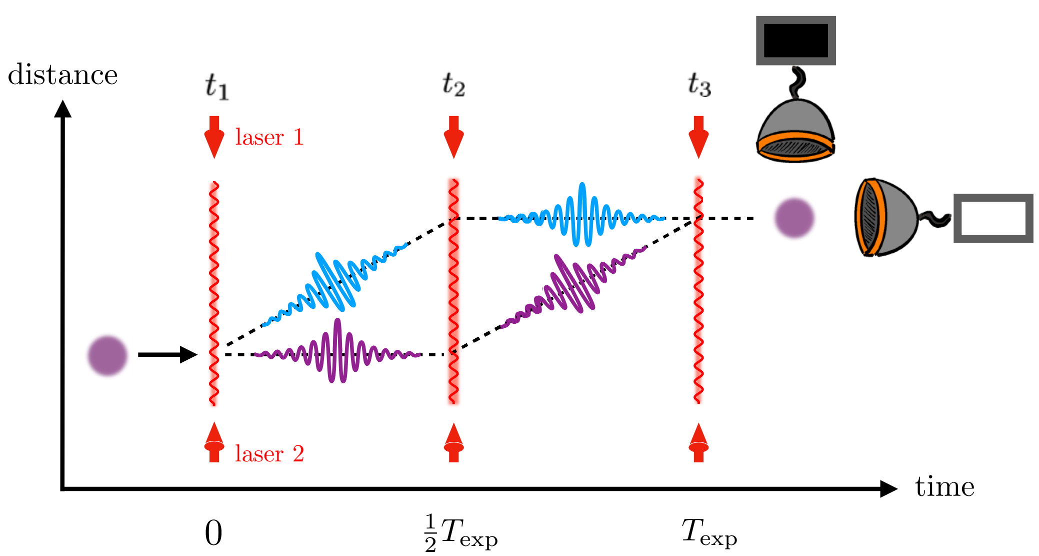
Quantum sensors

accelerometers

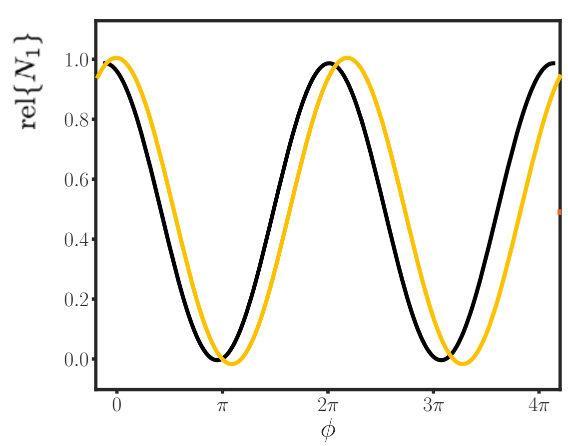




e.g. optical & atom interferometers



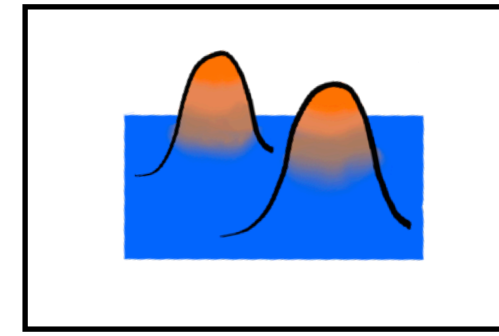
$$\rho_1 = \frac{1}{2}\begin{pmatrix} 1 & e^{i(\phi+\Delta\phi)} \\ e^{-i(\phi+\Delta\phi)} & 1 \end{pmatrix}$$



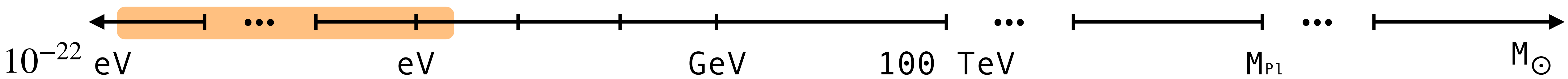
[Ippei Obata on Mon]

Quantum sensors

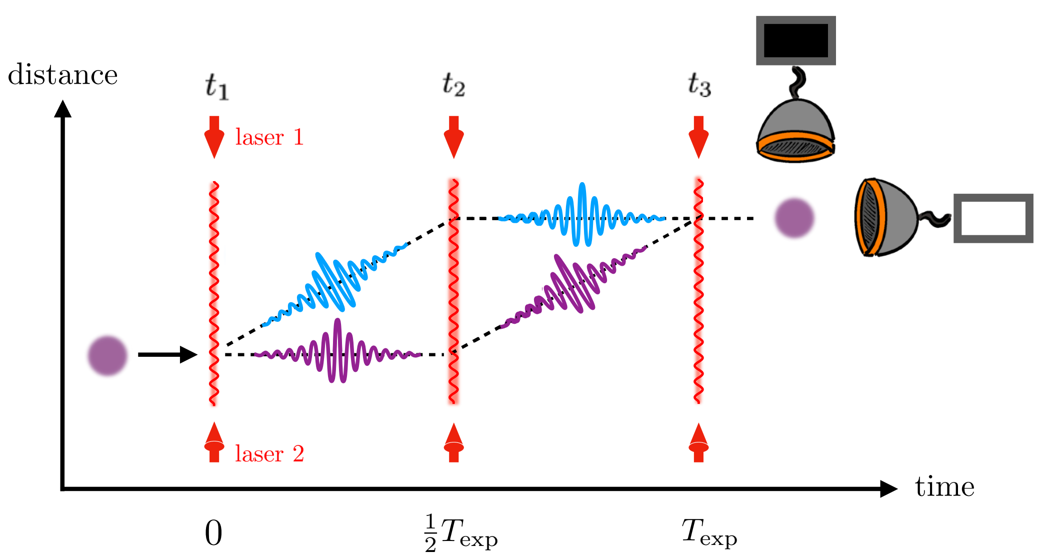
accelerometers



[Xucheng Gan today]



e.g. optical & atom interferometers



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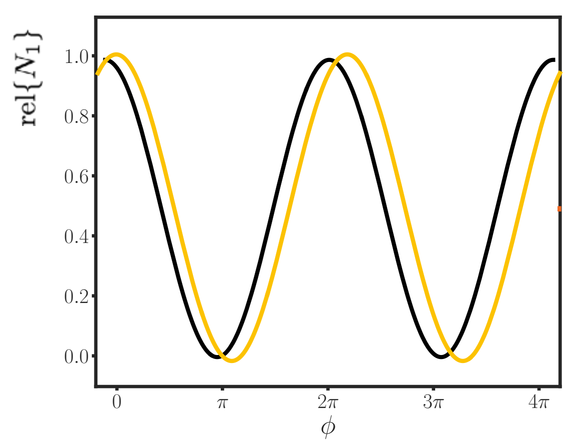
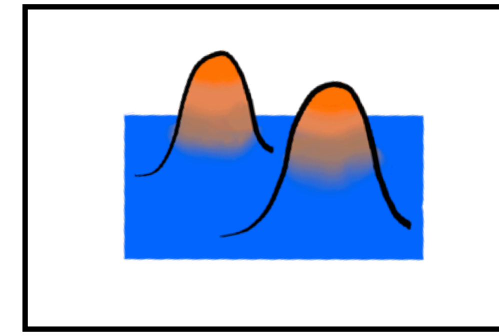
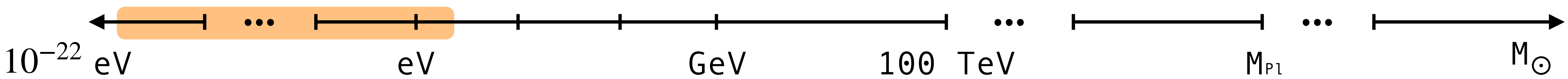


[Ippei Obata on Mon]

Quantum sensors

~~accelerometers~~
gyroscopes





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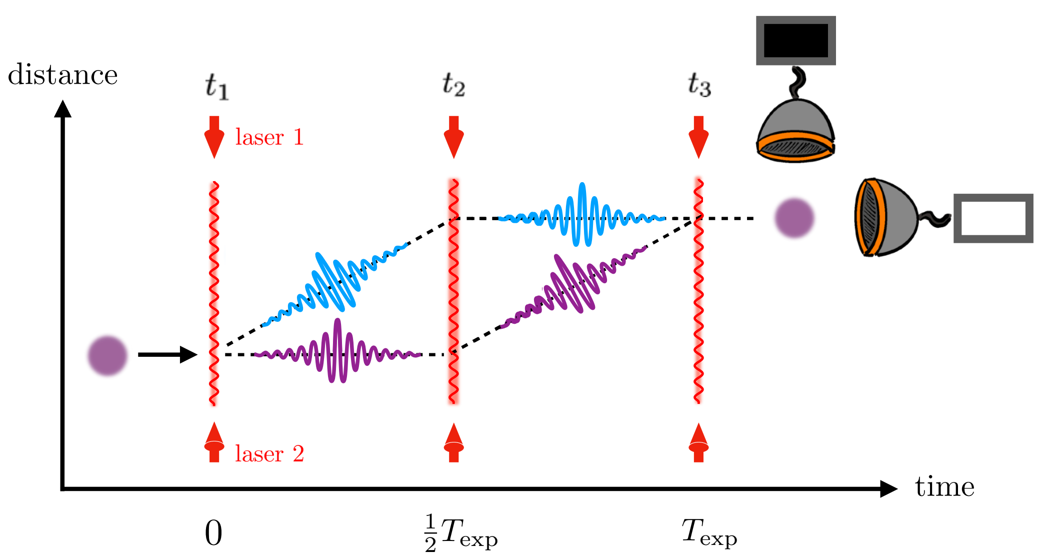

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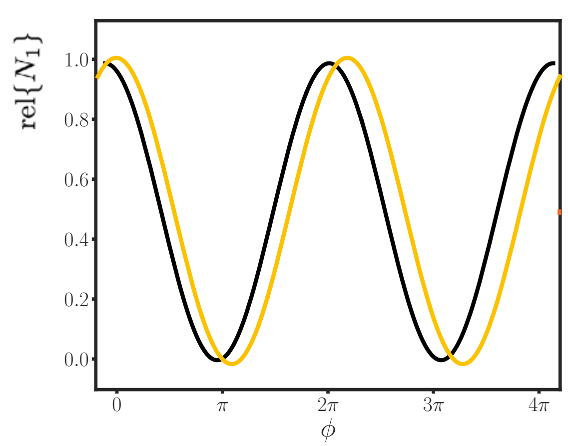
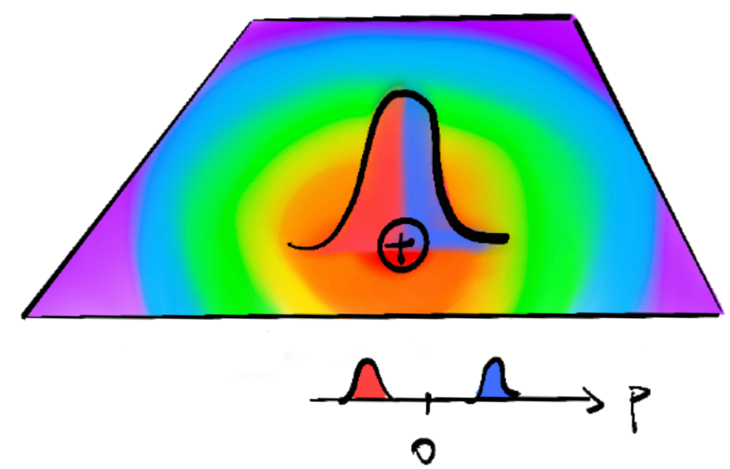


[Ippei Obata on Mon]

Ion interferometers

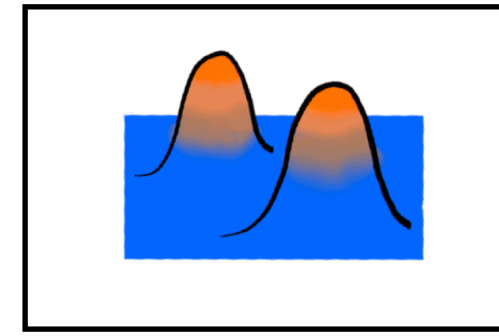


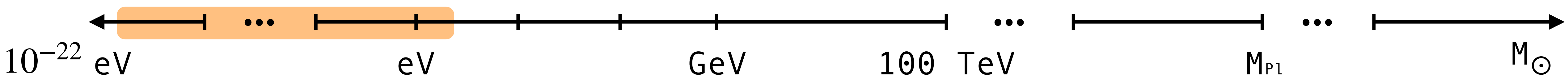
[Leonardo Badurina today]

Quantum sensors

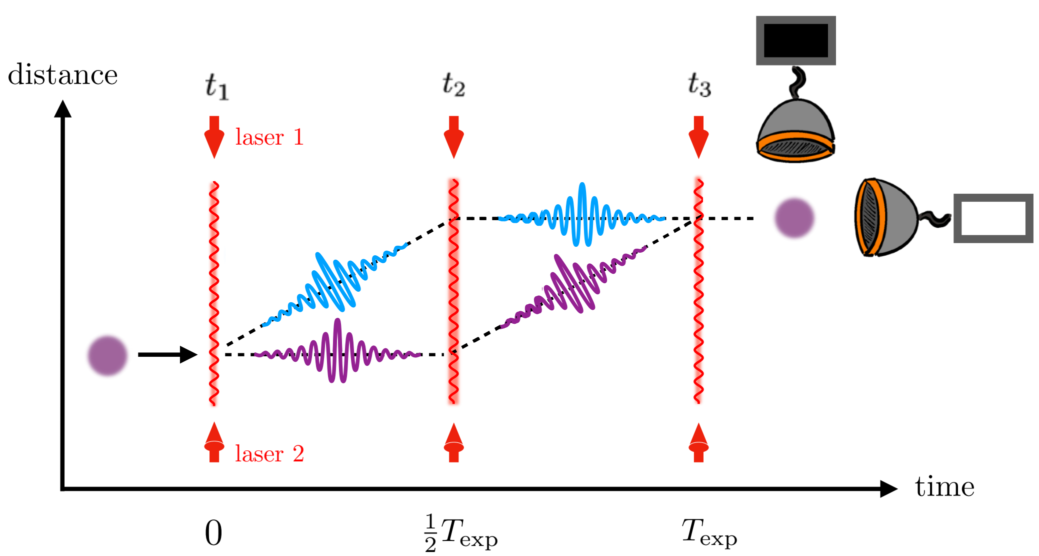
~~accelerometers~~

gyroscopes





e.g. optical & atom interferometers



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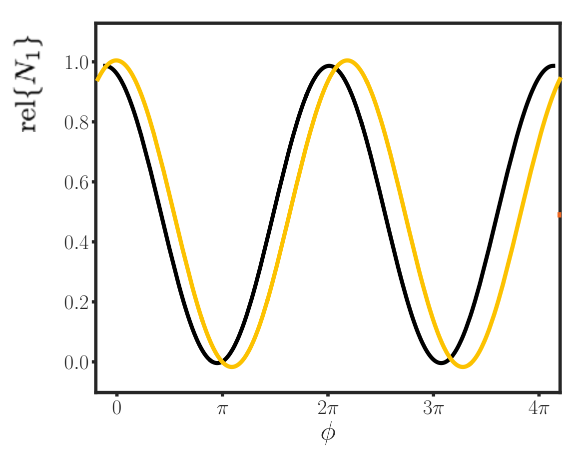
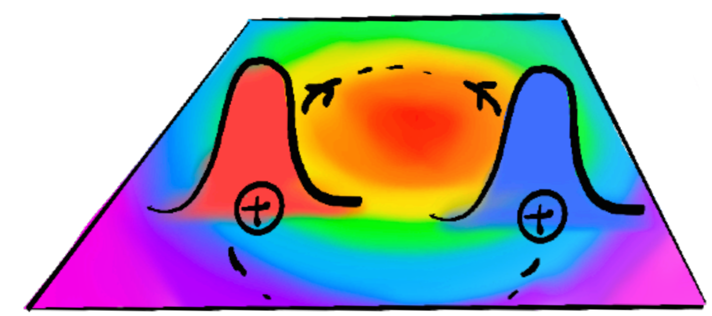


[Ippei Obata on Mon]

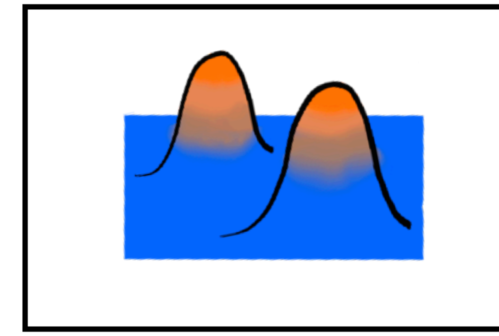
Ion interferometers

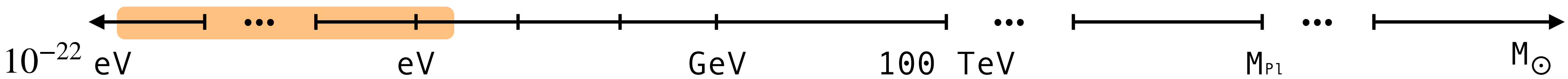


[Leonardo Badurina today]

Quantum sensors

~~accelerometers~~
gyroscopes





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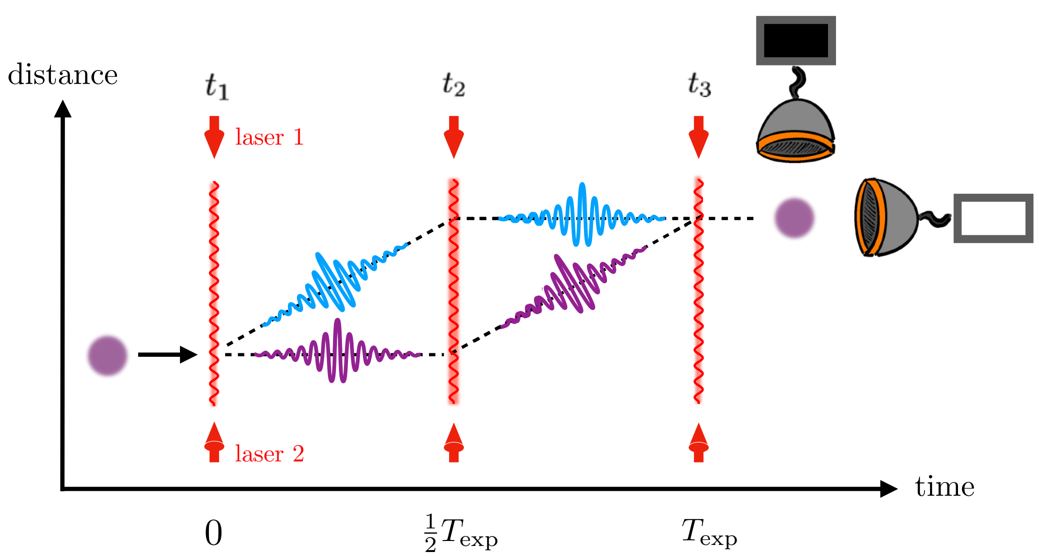

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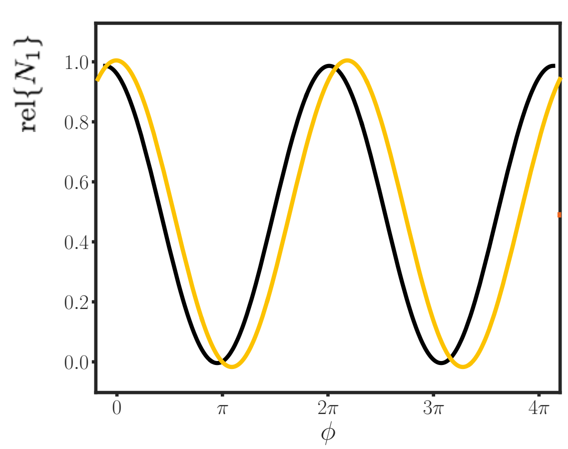
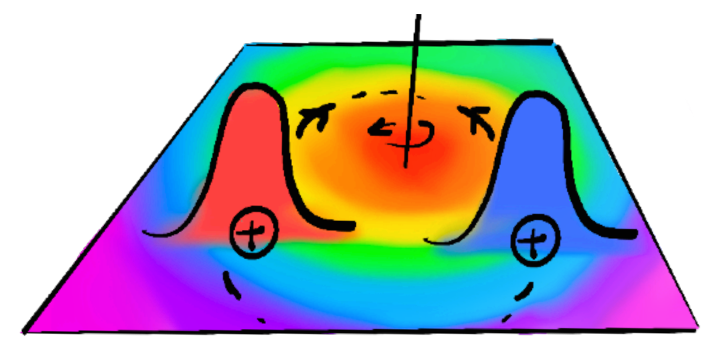


[Ippei Obata on Mon]

Ion interferometers



Sagnac effect

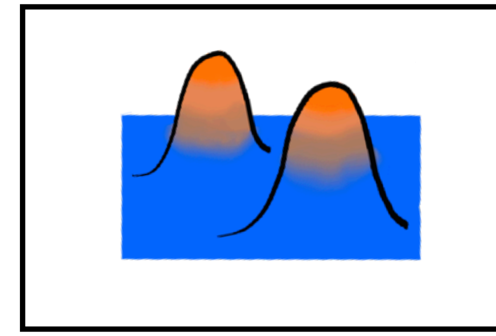
$$\Delta\phi \approx \frac{8\pi}{\lambda c}\boldsymbol{\omega}\cdot\mathbf{A}$$

[Feddereke, Graham, Kimball, Kalia, 2021]

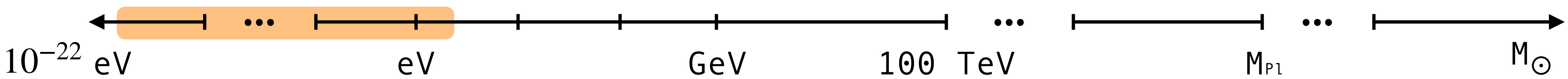
[Leonardo Badurina today]

Quantum sensors

accelerometers

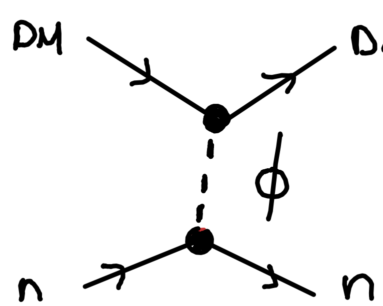


Atom gradiometers can be sensitive to pure gravitational interactions [Badurina et al.,’25]

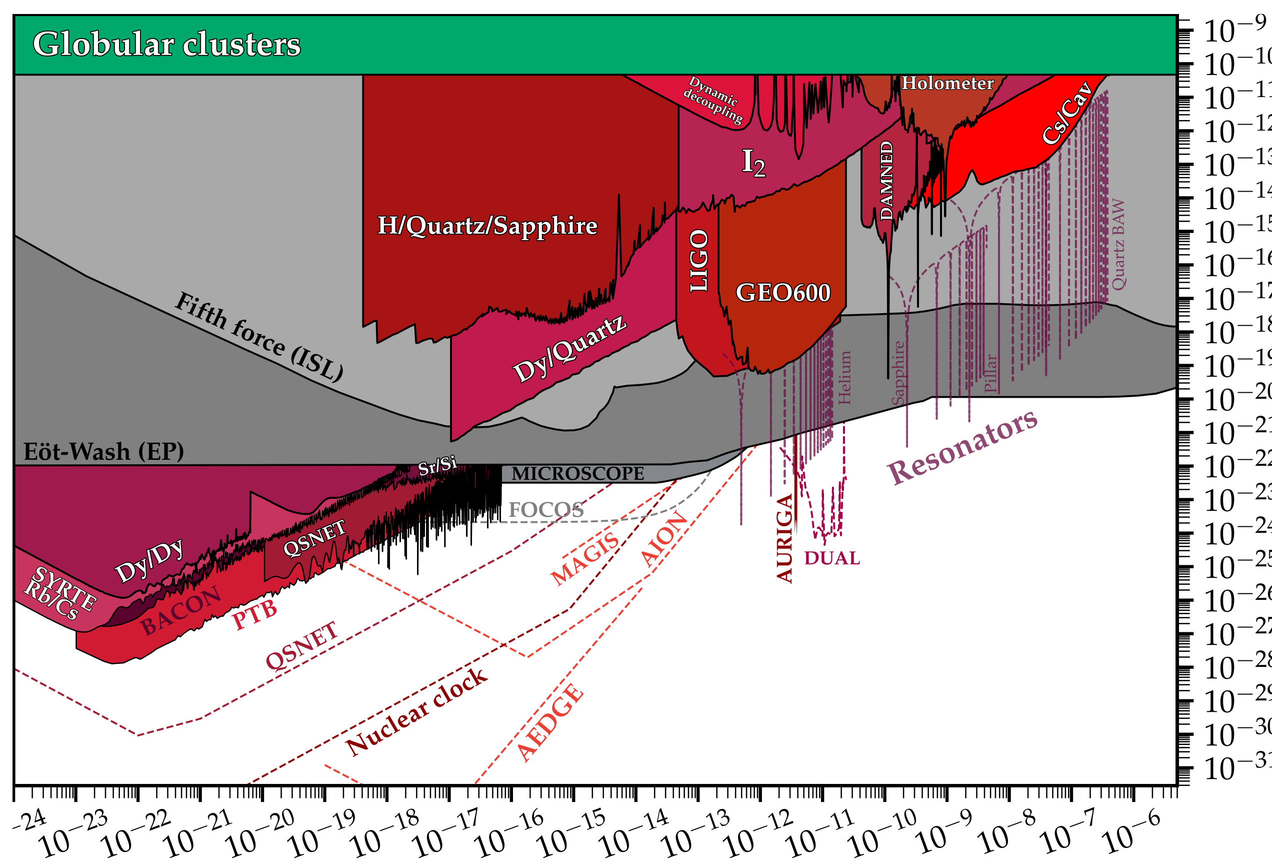


scalar $\mathcal{L} \supset g_{\phi\gamma}\langle\phi\rangle FF + g_{\phi G}\langle\phi\rangle GG - g_f\langle\phi\rangle \bar{f}f + \text{h.c.}$

5th force searches



$$\Rightarrow V(r) = -\frac{y_n^2}{4\pi}\frac{1}{r}e^{-m_\phi r}$$



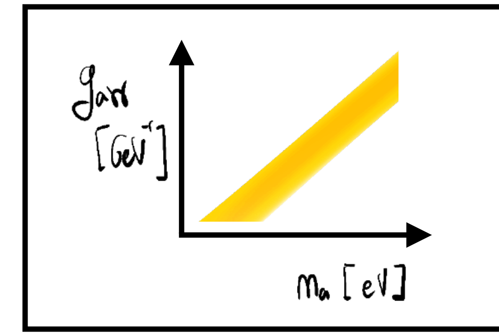
scalar-photon coupling [GeV^{-1}]

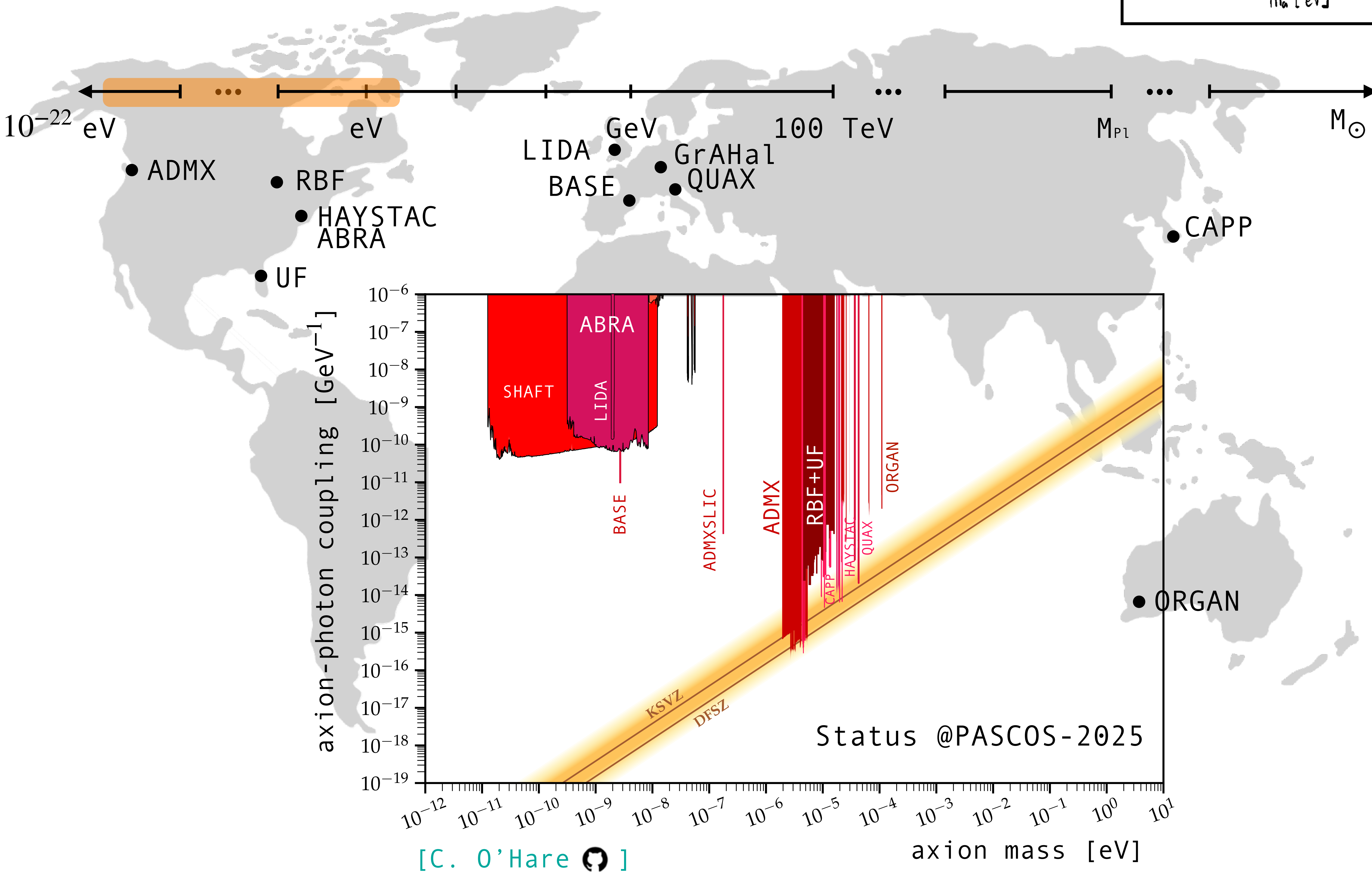
[C. O’Hare] scalar mass [eV]

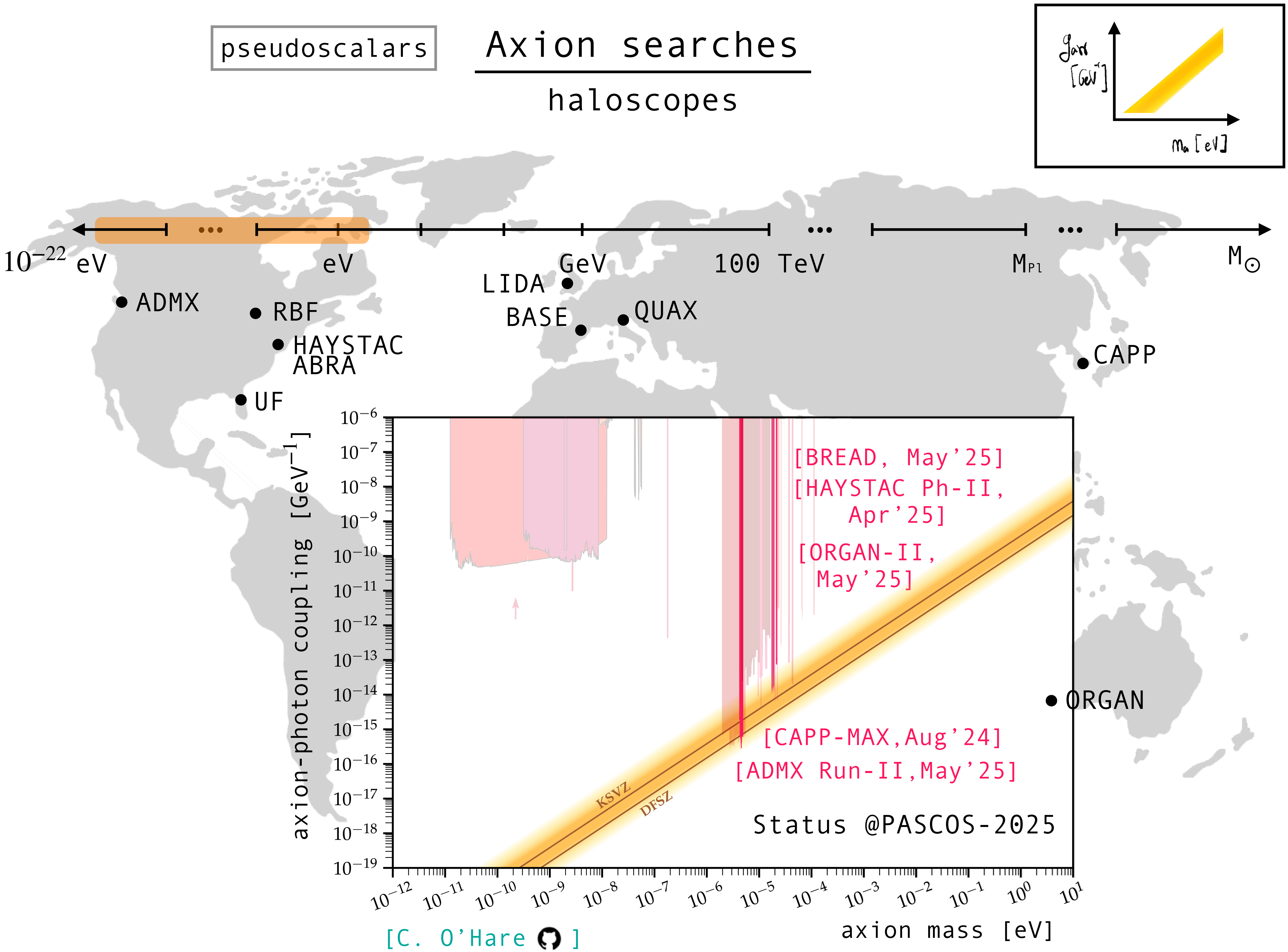
pseudoscalars

Axion searches

haloscopes



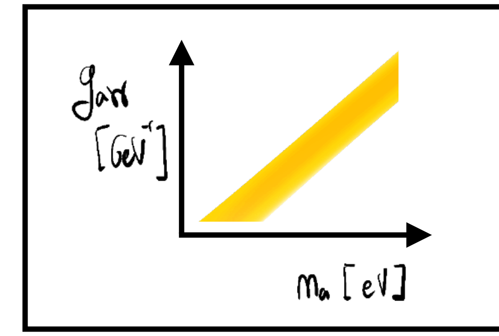


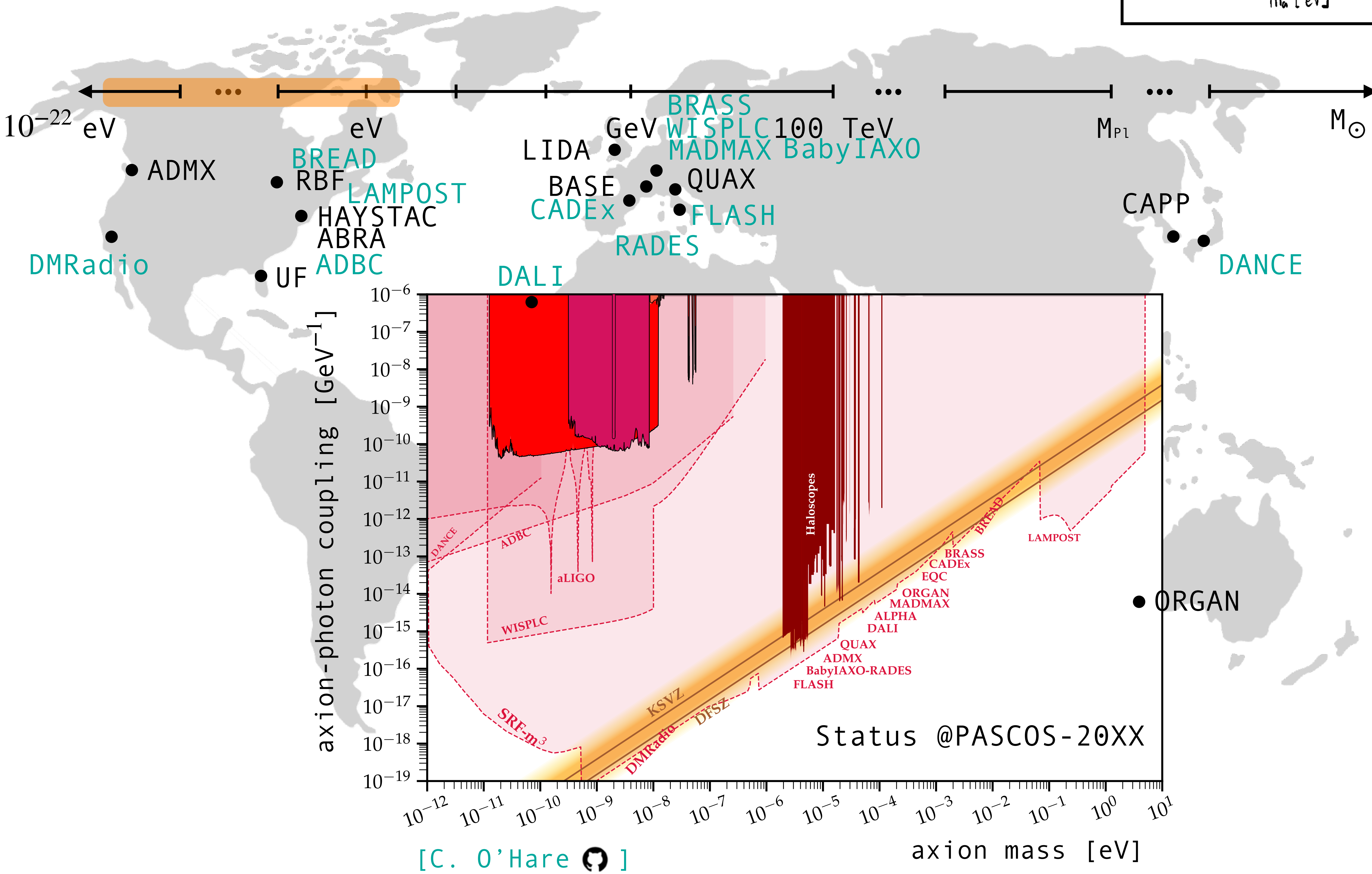

pseudoscalars
Axion searches
haloscopes
$g_{a\gamma\gamma}$ [GeV^{-1}]
m_a [eV]
10^{-22} eV
eV
GeV
100 TeV
M_{Pl}
$M_\odot$
ADMX
RBF
HAYSTAC
ABRA
UF
LIDA
BASE
QUAX
CAPP
ORGAN
[BREAD, May'25]
[HAYSTAC Ph-II, Apr'25]
[ORGAN-II, May'25]
[CAPP-MAX, Aug'24]
[ADMX Run-II, May'25]
KSVZ
DFSZ
Status @PASCOS-2025
axion-photon coupling [GeV^{-1}]
axion mass [eV]
[C. O'Hare]

pseudoscalars

Axion searches

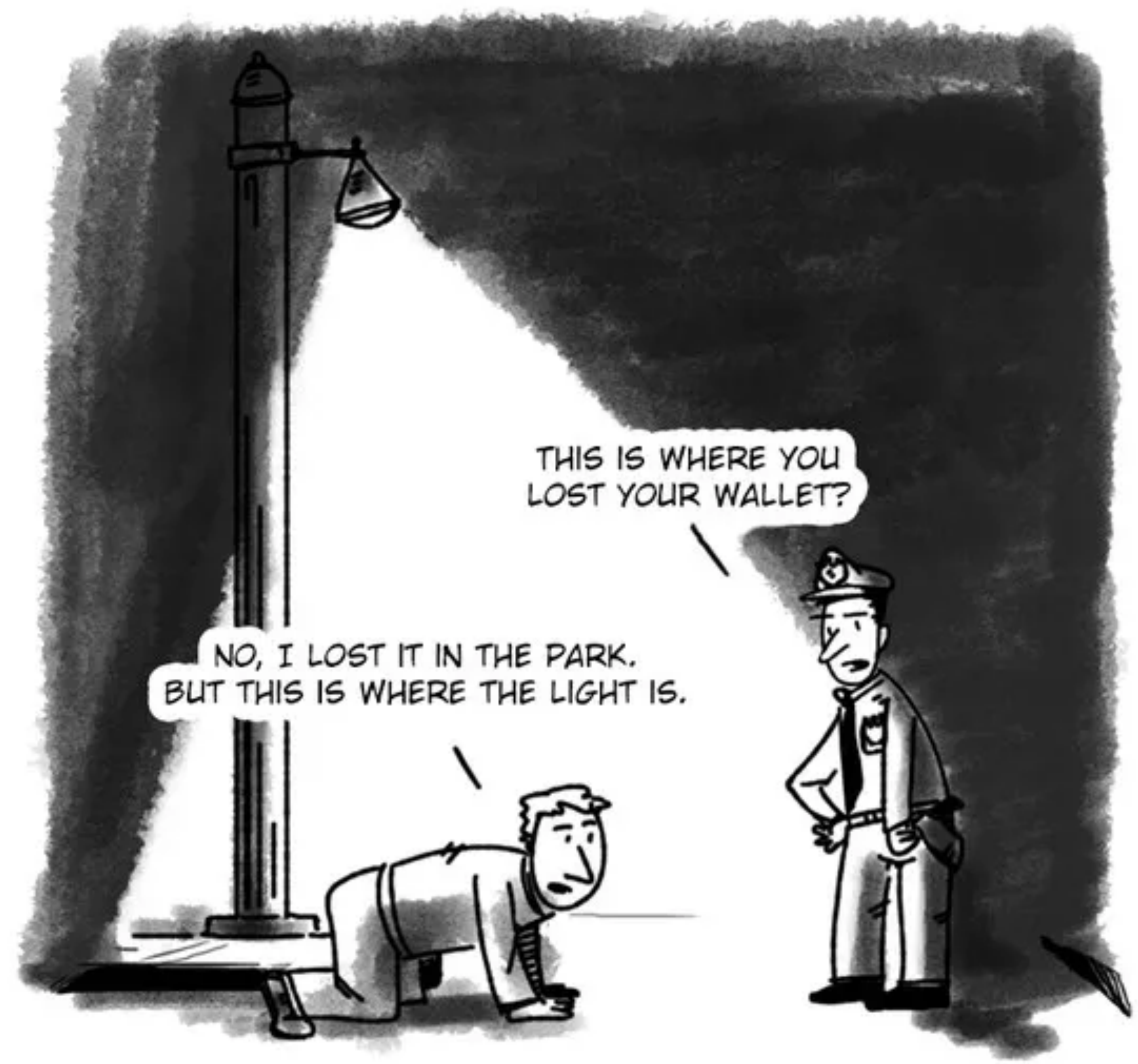
haloscopes





Conclusions

Energy(GeV)



Conclusions

Energy(GeV)

New parameter space is being
and will be accessed.

DIALOG between communities
is crucial. Joint efforts.

Dark matter searches can be
parasitic to other existing
experimental searches.

Stay tunned!