# Dark anti-atoms

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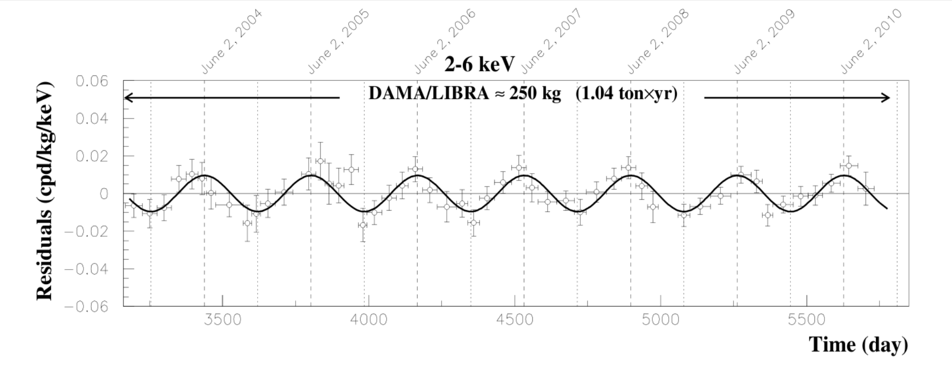
Q. Wallemacq, J.R. Cudell, arXiv:1411.3178

# Introduction

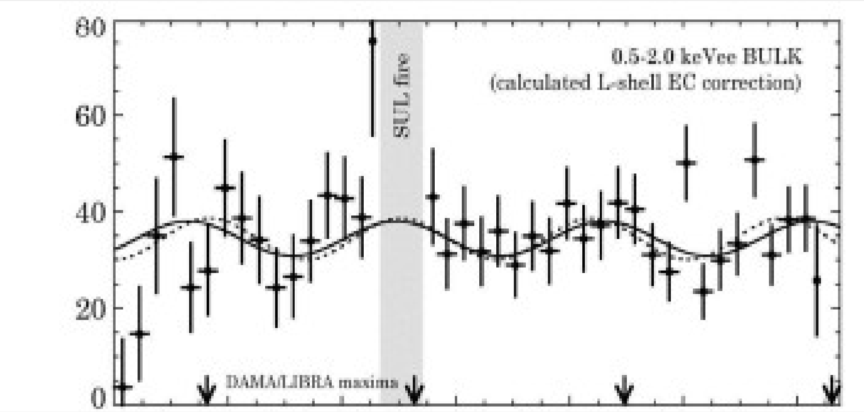
## The status of direct-search experiments

• **DAMA/LIBRA:**




Annual modulation of the event rate at the 9.3σ C.L. in the (2-6) keV energy interval

• **CoGeNT:**




Annual modulation of the bulk events at the 2.2σ C.L. in the (0.5-2) keV energy interval

•**CDMS-II/Si:** 3 nuclear recoils at 8.2, 9.5 and 12.3 keV with a 5%-probability to be due to background

• **CDMS-II/Ge, superCDMS, XENON100, LUX:** No signal that cannot be explained by background

# Introduction

## The status of direct-search experiments

Rules of the game: - DAMA/LIBRA annual modulation at the 9.3σ C.L. exists and is **due to DARK MATTER**! ✓

- CoGeNT annual modulation does not exist ✗
  *Davis et al. (2014)*

- CDMS-II/Si events are due to a fluctuation of the background ✗

- Ensure full consistency with the null results from CDMS-II/Ge, superCDMS, XENON100 and LUX ✓

# Dark anti-atoms

## The model

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  and ELECTRON RECOILS (X/γ-ray photons, charged particles,...)

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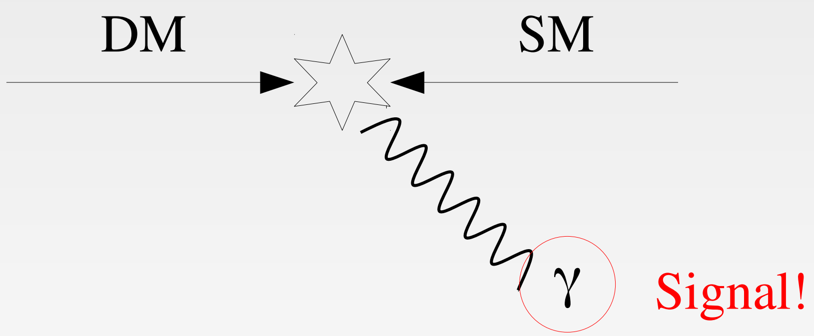
- Thermal DM particles: formation of BOUND STATES with atoms in the detector



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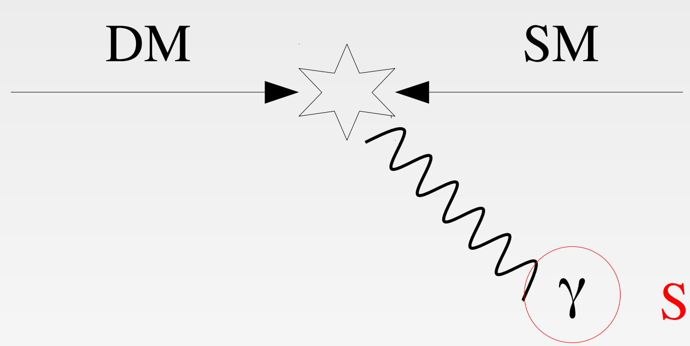



Signal!

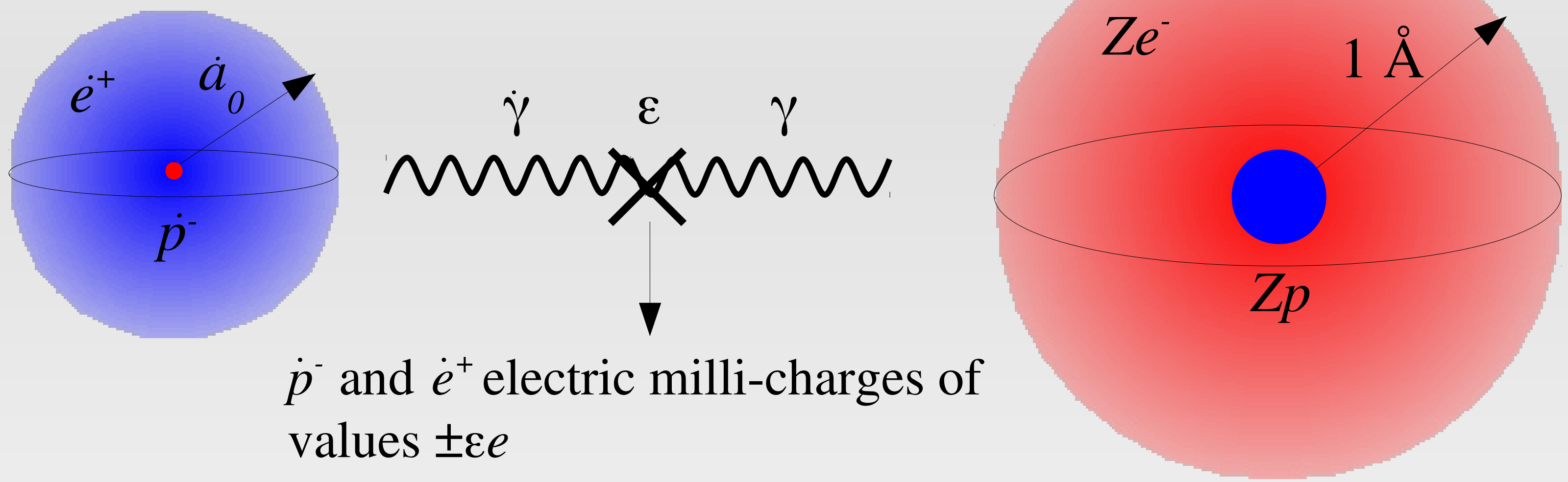
- Bound state: need for an attractive interaction $\longrightarrow$ Dark anti-atoms

# Dark anti-atoms

## The model

Dark anti-hydrogen atom

Standard atom




$\dot{p}^-$ and $\dot{e}^+$ electric milli-charges of values $\pm\varepsilon e$

*Holdom (1986), Foot (2000), Feldman et al. (2007), Cline (2012)*

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## The model

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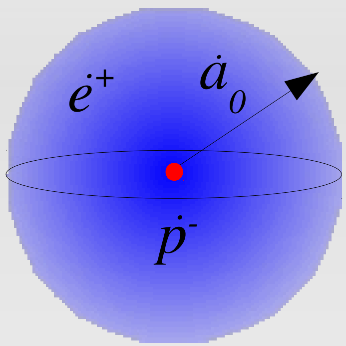
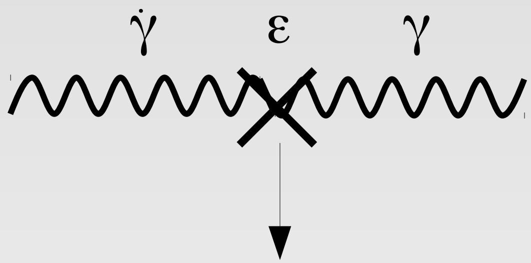
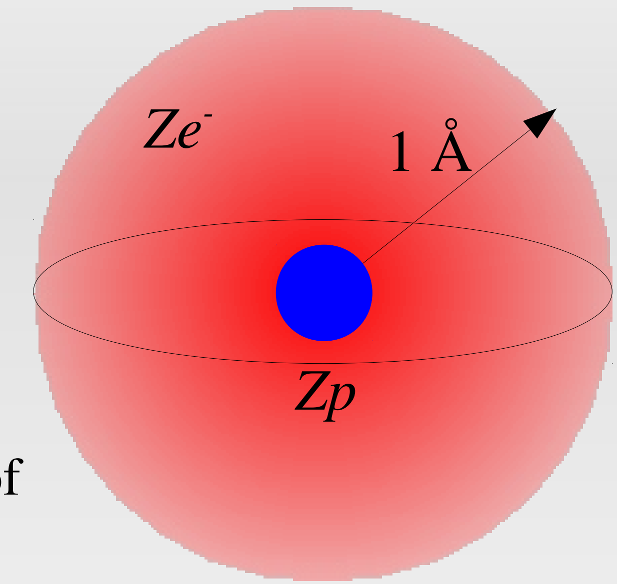



Standard atom

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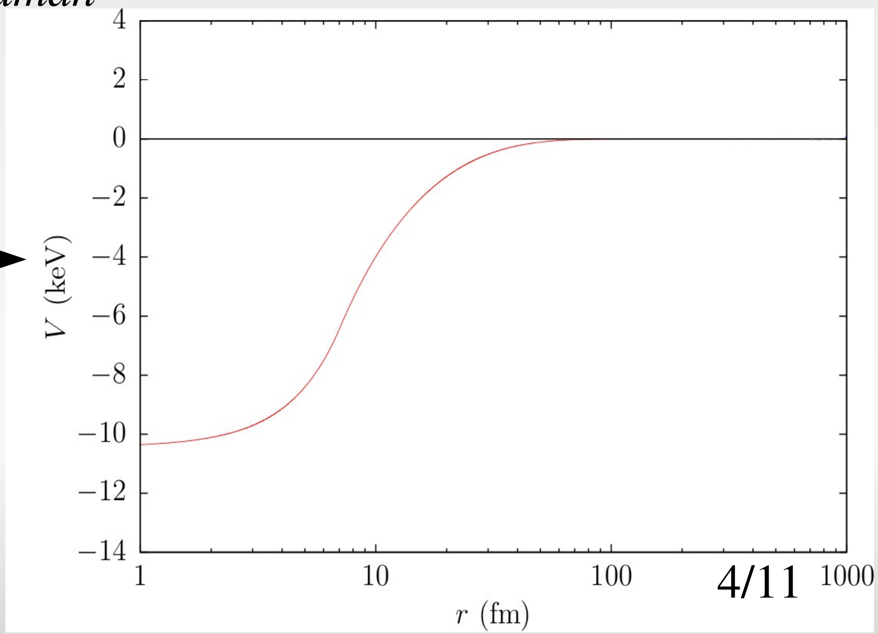
<u>3 model parameters</u>: $m$ ~ 1 TeV ($m=m_{\dot{p}}>>m_{\dot{e}}$)

$\varepsilon \sim 5.10^{-4}$

$\dot{a}_0 \sim 30$ fm



# Constraints on milli-charges

From cosmology, astrophysics:

- Cooling of red giants and white dwarfs
  *Raffelt (1996), Davidson et al. (2000)*
- Big Bang Nucleosynthesis
  *Davidson et al. (2000)*

$\varepsilon < 10^{-14}$ for $m_{\dot{p}}$, $m_{\dot{e}} < 1$ MeV

$\longrightarrow$ OK since $m_{\dot{p}} \sim 1$ TeV

$m_{\dot{e}} \sim 1$ GeV

From laboratory:

- Invisible decay of positronium: $\varepsilon <$ 3.4 $10^{-5}$ for $m_{\dot{p}}$, $m_{\dot{e}} < m_e$ $\longrightarrow$ OK

*Badertscher et al. (2007)*

- Accelerators: $\varepsilon <$ 0.1 for $m_{\dot{p}}$, $m_{\dot{e}} > 1$ GeV $\longrightarrow$ OK

*Prinz et al. (1998)*

# Constraints on self-interacting DM

Self-interacting dark matter:

Constraints from: Bullet cluster
Halo shapes
Formation of a dark disk
*Randall et al. (2013)*

SUBDOMINANT dark sector: at most 5% of total dark mass of halos

$\rho_{\text{dark atoms}} = f\,\rho_{\text{local}}$

$\rho_{\text{local}}$ = 0.3 GeV/cm$^3$

# From space to underground detectors

## Thermalization in terrestrial matter

Dark matter wind → Dark atoms hit the surface of the earth

↓

Lose energy ← Undergo elastic collisions with terrestrial atoms

↓

- Energy loss per unit path length: $\frac{dE}{dx}$
- Penetration length: $x = \int_{E_{th}}^{E_0} \frac{dE}{|dE/dx|}$ $< 1$ km Typical depth of underground detectors

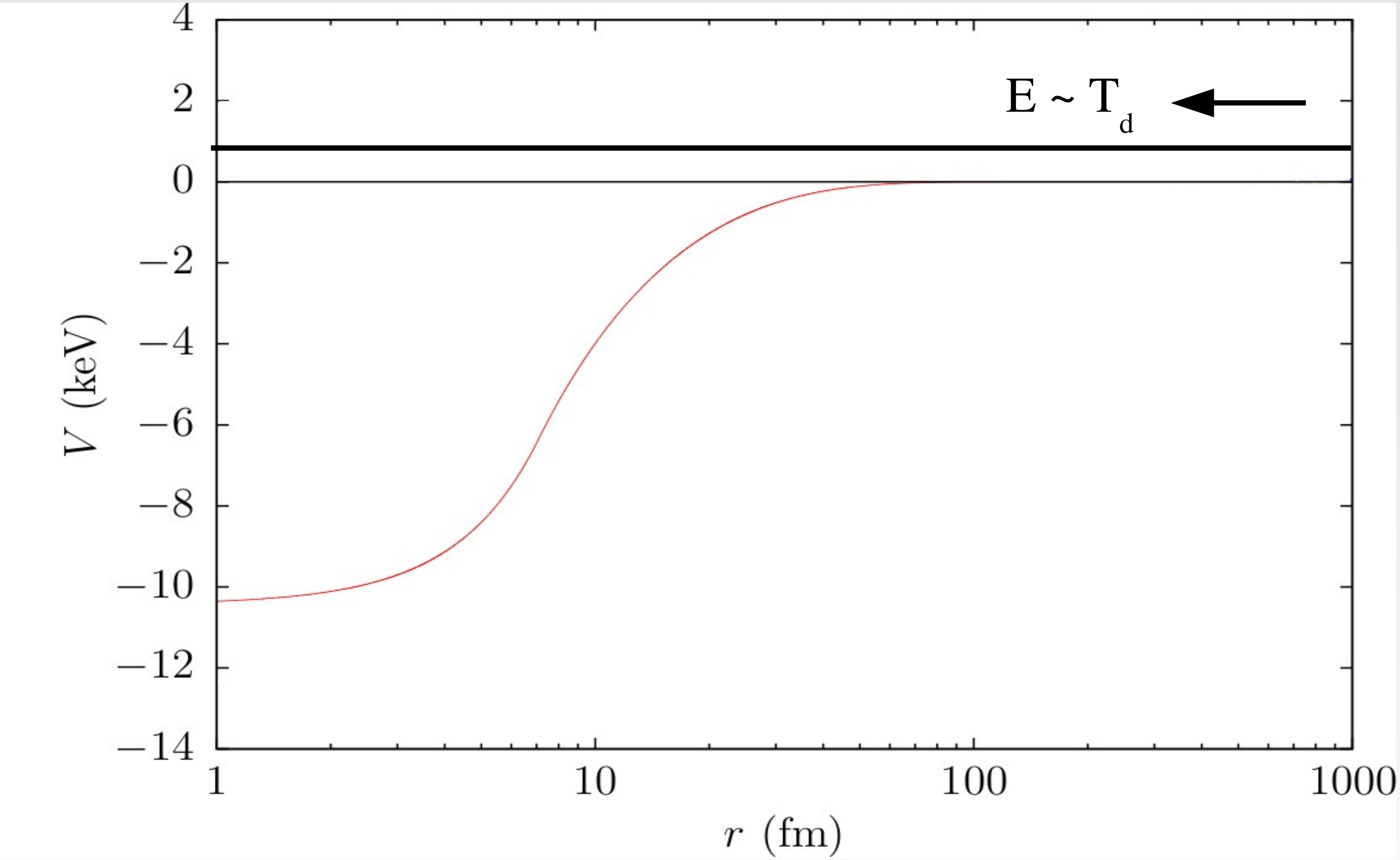
↓

Drift towards the center of the earth (~10 cm/s) → Reach underground detector with thermal energies

# From space to underground detectors

## Bound-state-formation events

Radiative capture of thermal dark anti-atoms by atoms of the active medium:



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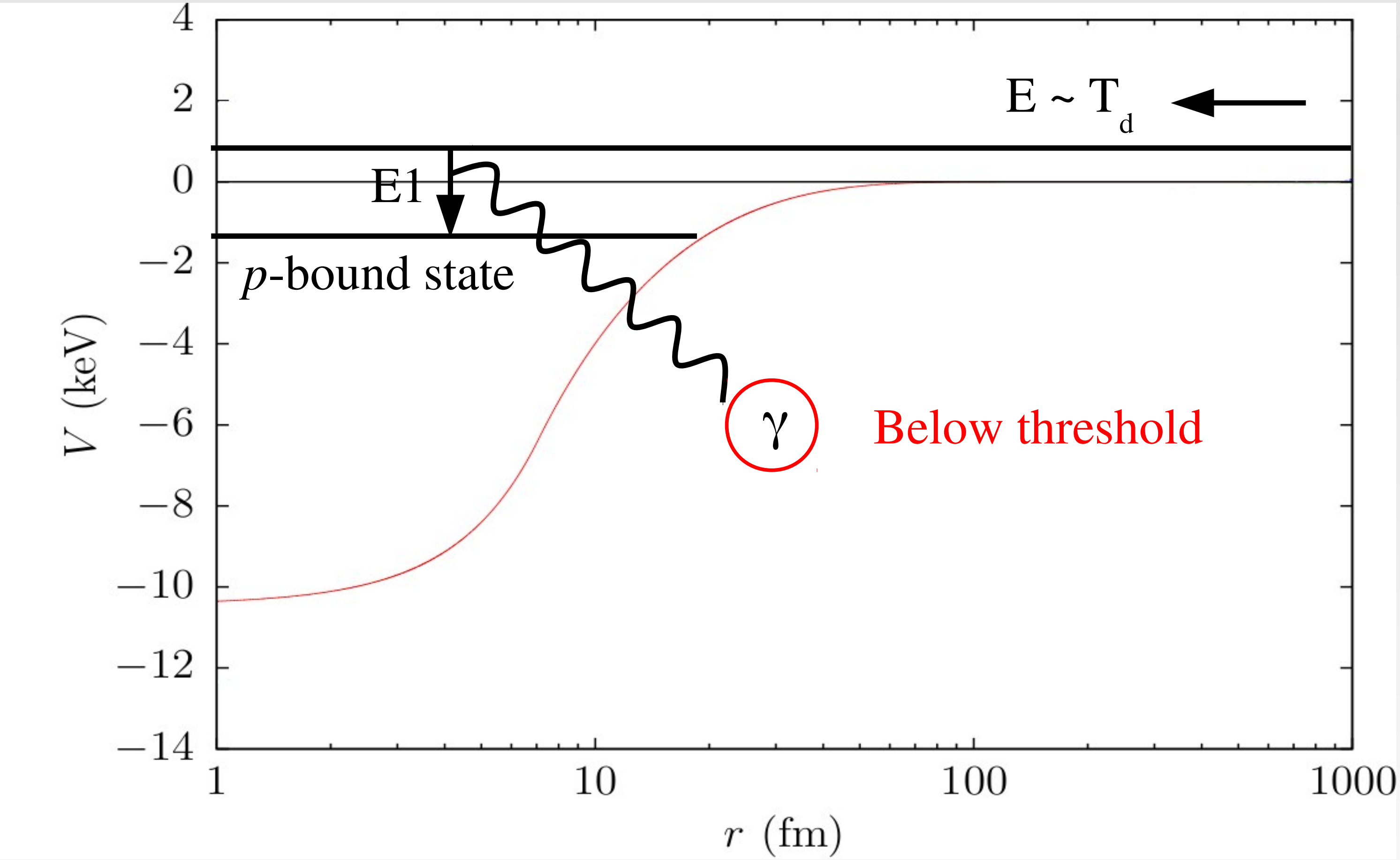

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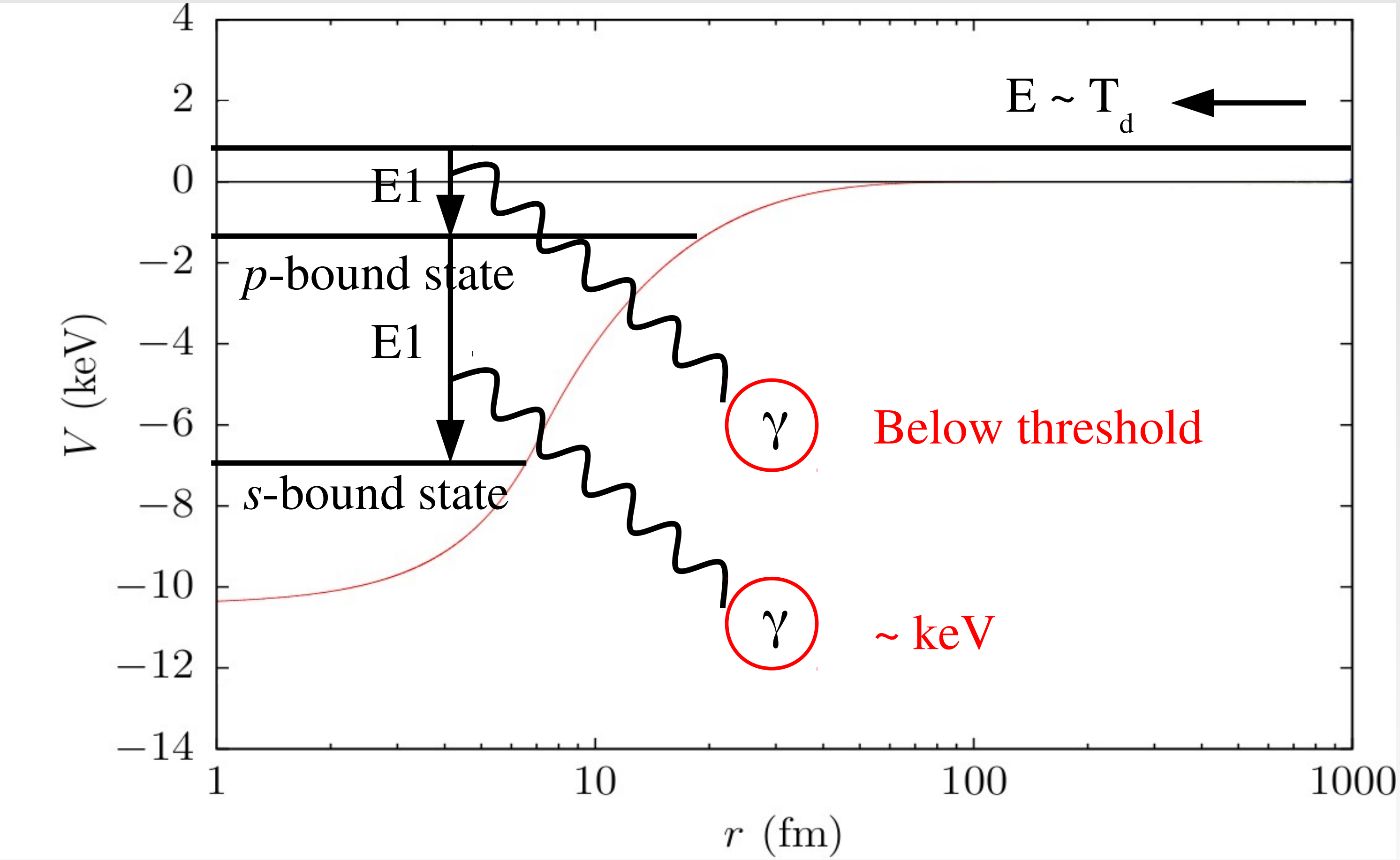

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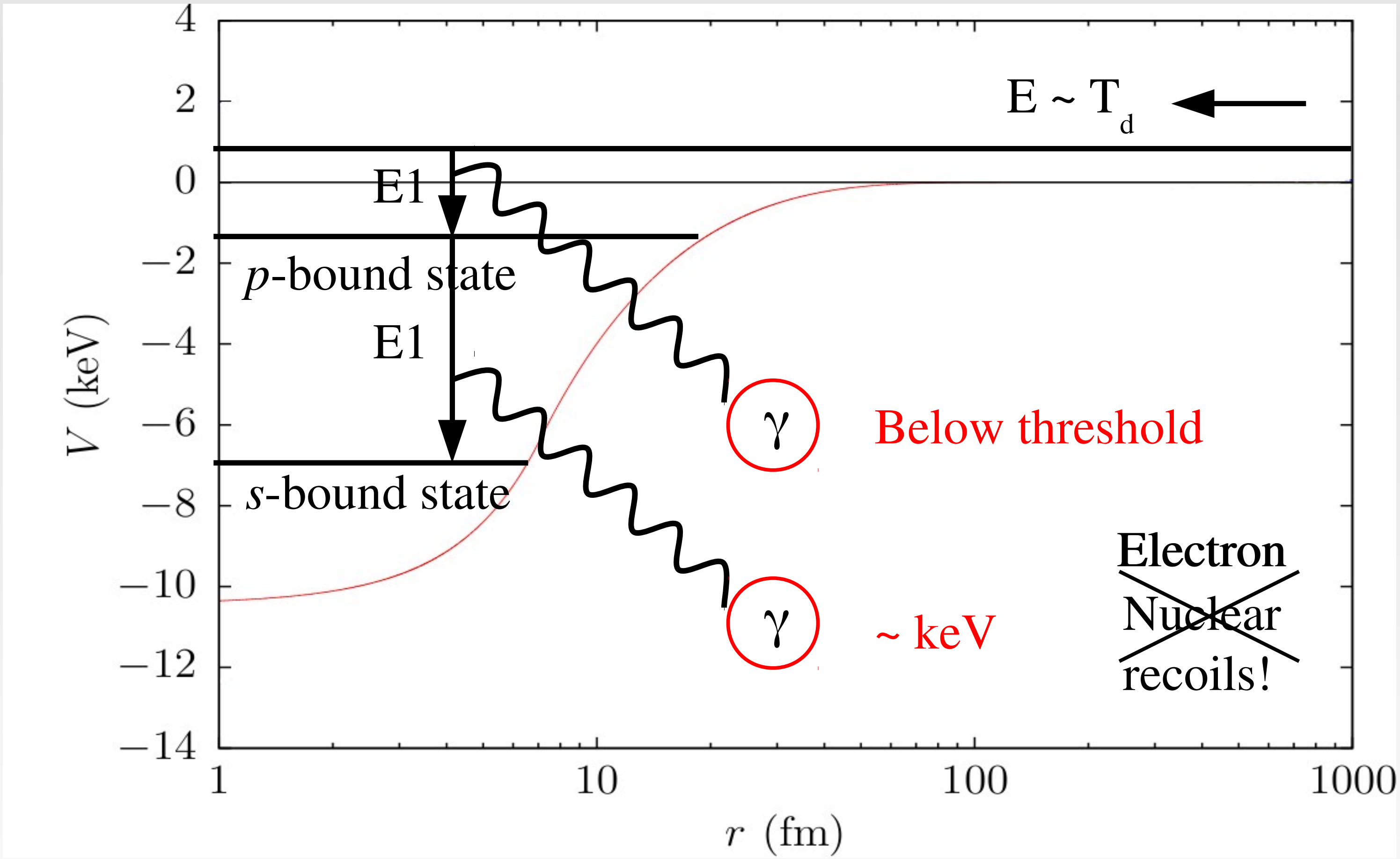



Bound-state-formation rate: $R \sim \langle \sigma_{capt} v \rangle$ → Maxwell-Boltzann velocity distribution at T$_d$

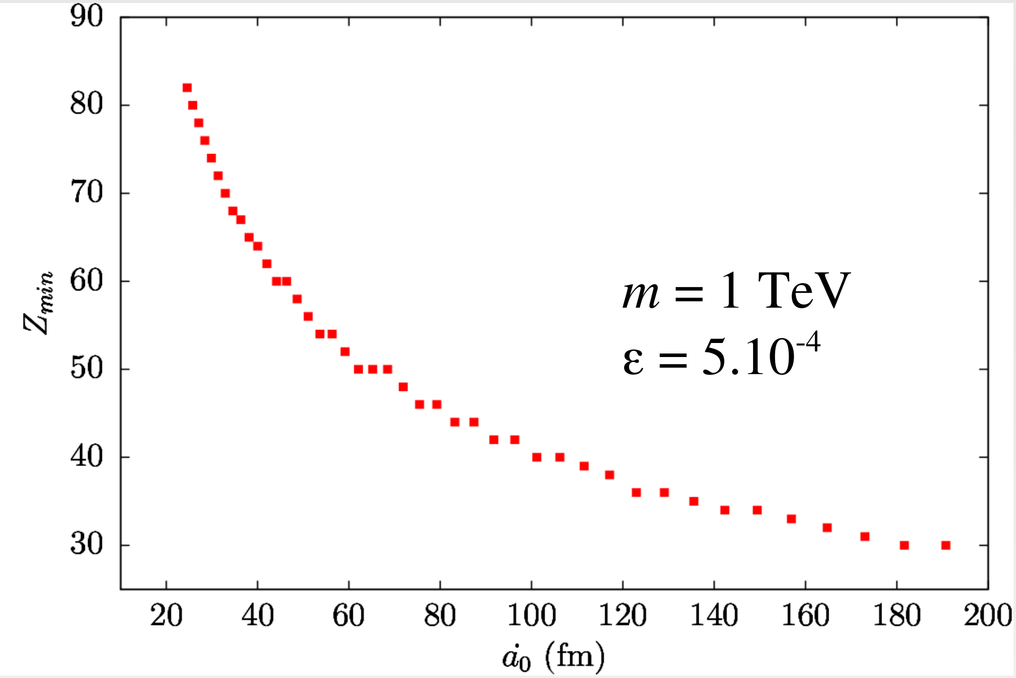
# Binding to very heavy elements

DAMA/LIBRA annual modulation: R ~ 0.04 cpd/kg

→ Requires small values of $\dot{a}_0$ ~ 30 fm

→ Strong screening

→ Binding only to high-Z elements ($Z > Z_{min}$)



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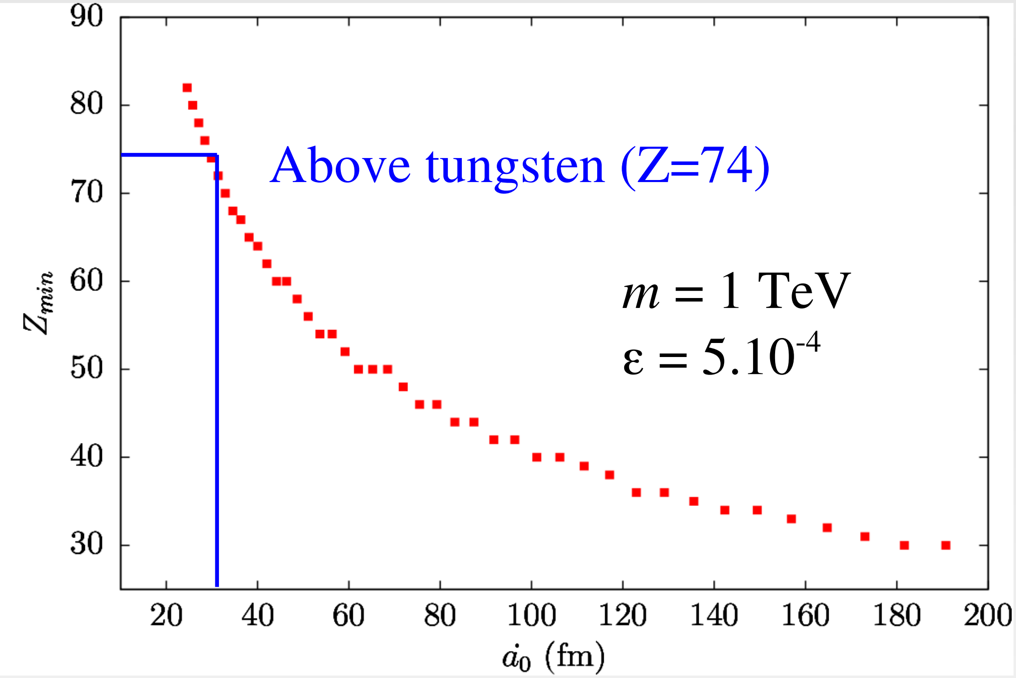

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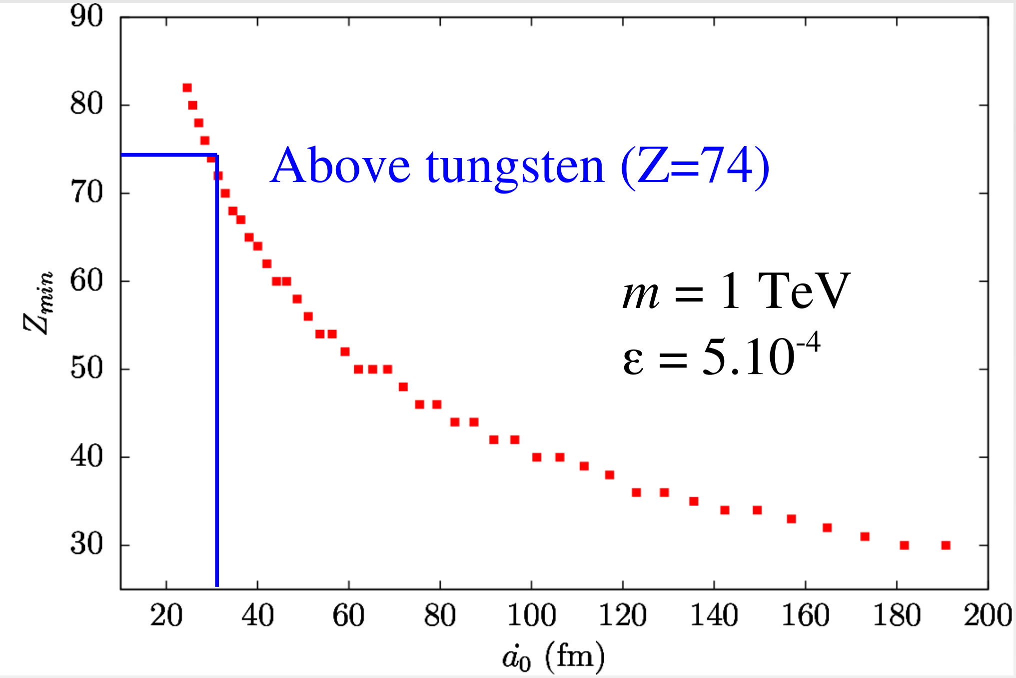


- **DAMA: NaI(Tl) crystal**
  **Binding to thallium (Z=81) dopant present at the $10^{-3}$ level**

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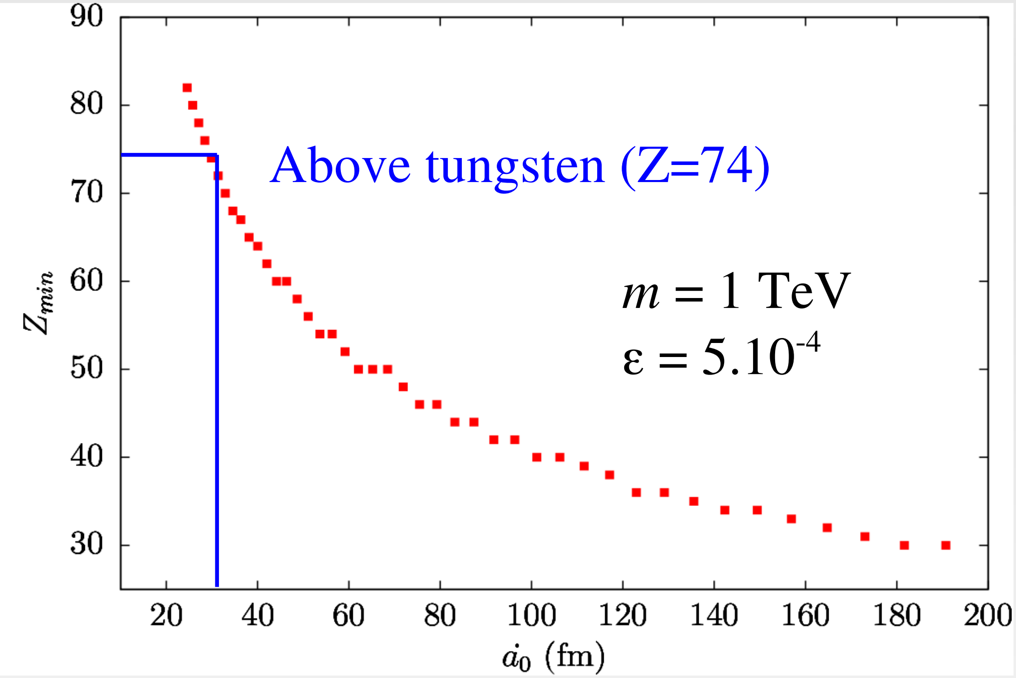


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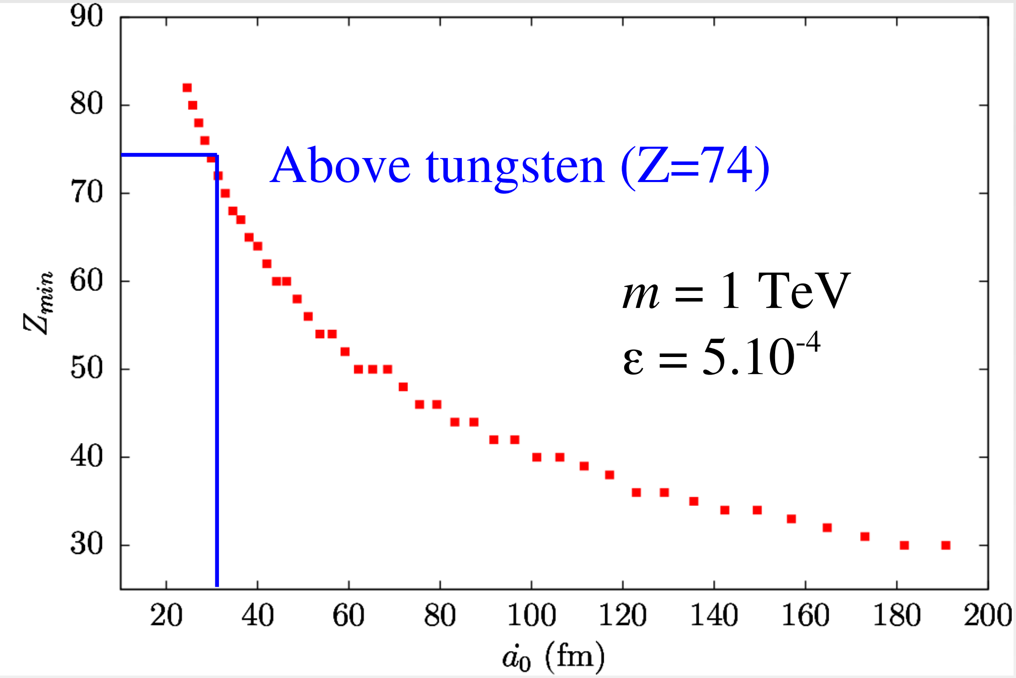


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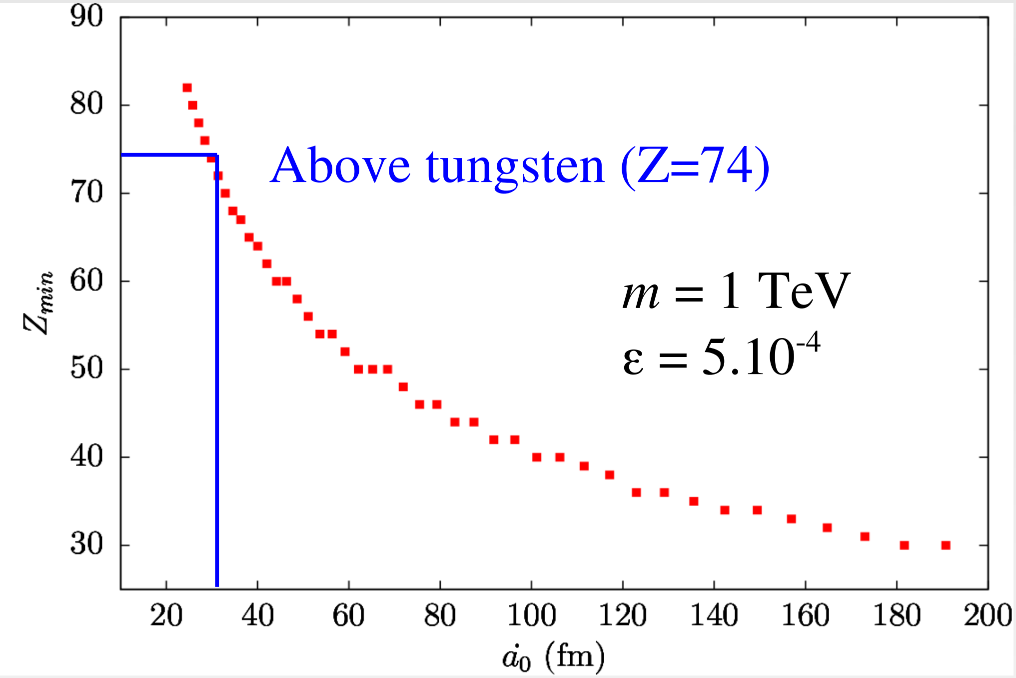


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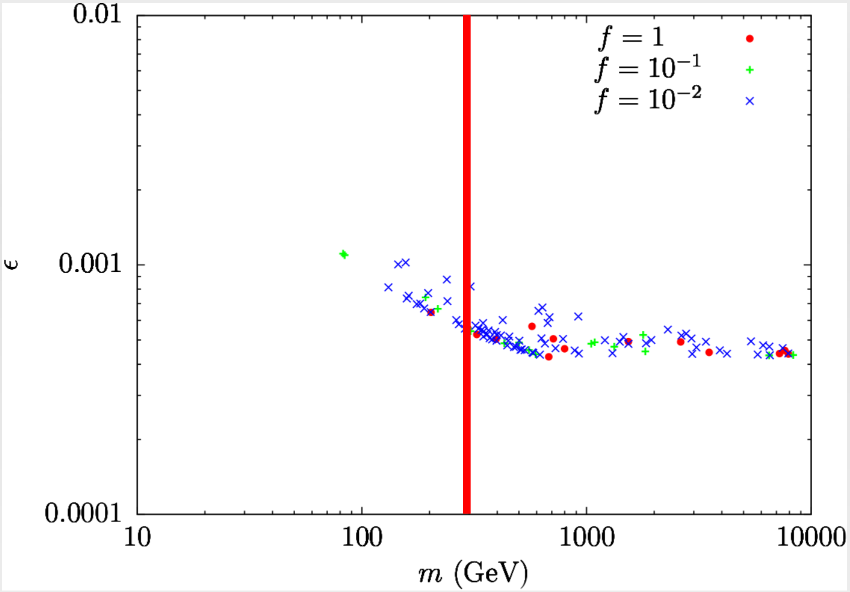
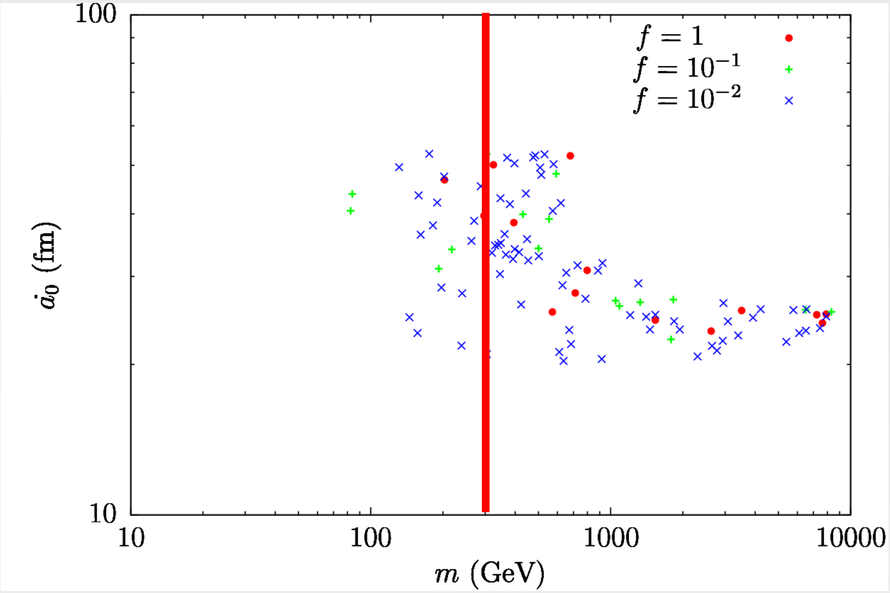
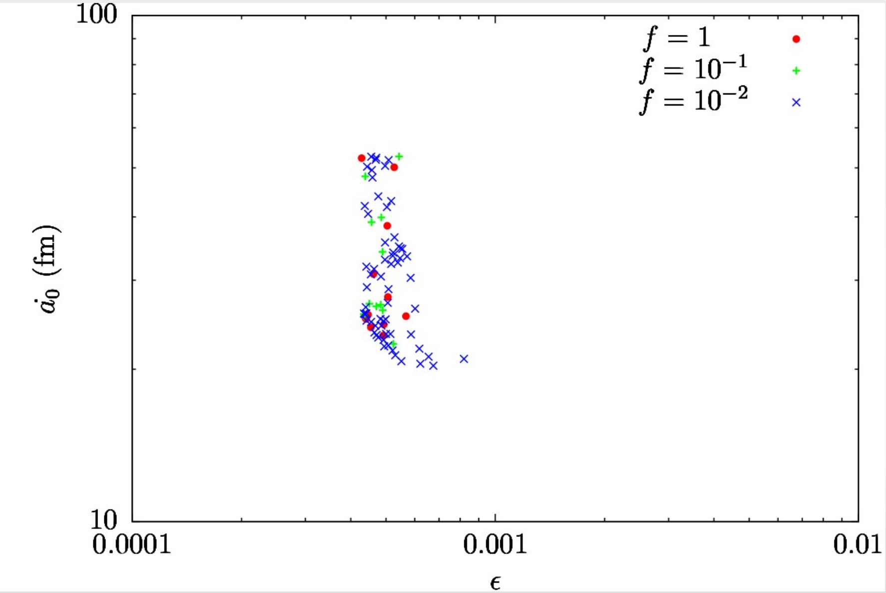
- Elastic collisions in crust (silicon Z=14)
- Only pay attention to lead (Z=82) in crust and shieldings
- No bound state with germanium, xenon → Consistent with CDMS-II/Ge, superCDMS, XENON100, LUX (CoGeNT, CDMS-II/Si)

# Results

## DAMA modulation + constraints/requirements




Limit from production of ”superheavy” isotopes of heavy elements: ***m* > 300 GeV**

# Conclusions

- Sub-dominant dark sector made of dark anti-atoms interacting with standard sector through electric milli-charges

- Thermalization in terrestrial crust before 1 km deep

- Formation of bound states with atoms of the active medium

- Binding only to heavy elements ($Z > 74$)

- Explains: **DAMA, CDMS-II/Ge, superCDMS, XENON100, LUX**

- Does not explain (if signals actually present): **CoGeNT, CDMS-II/Si**

- <u>Predictions</u>: - one photon emitted below keV
  - emission of spectral lines
  - addition of high-Z material (thallium, lead,...) will enhance the signal

# Thank you!