Magnetic Bubble Chambers

Surjeet Rajendran
with
Phil Bunting, Giorgio Gratta, Michael Nippe, Jeffrey Long, Rupak Mahapatra and Tom Melia

The Dark Matter Landscape

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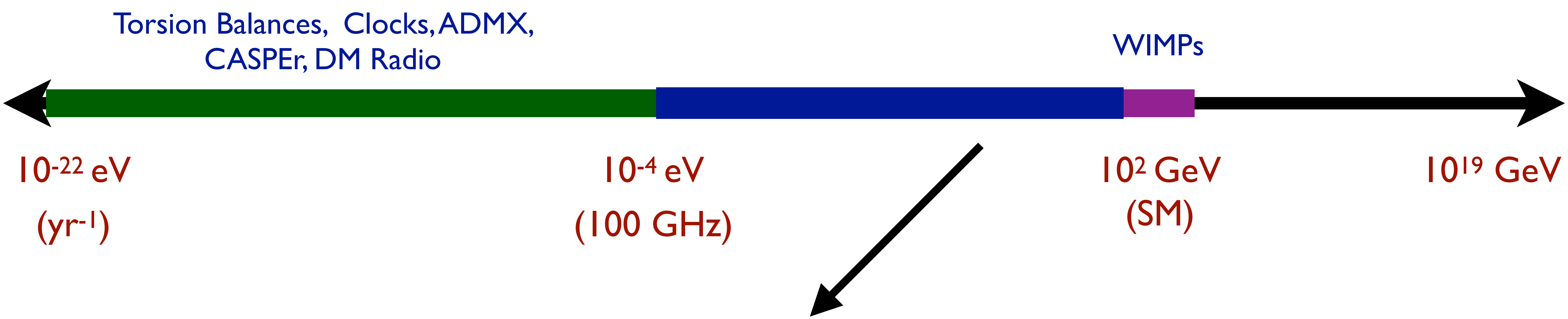

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Coherence time of signal too short for phase measurement to work. Energy deposition too small to be been using conventional WIMP calorimeters

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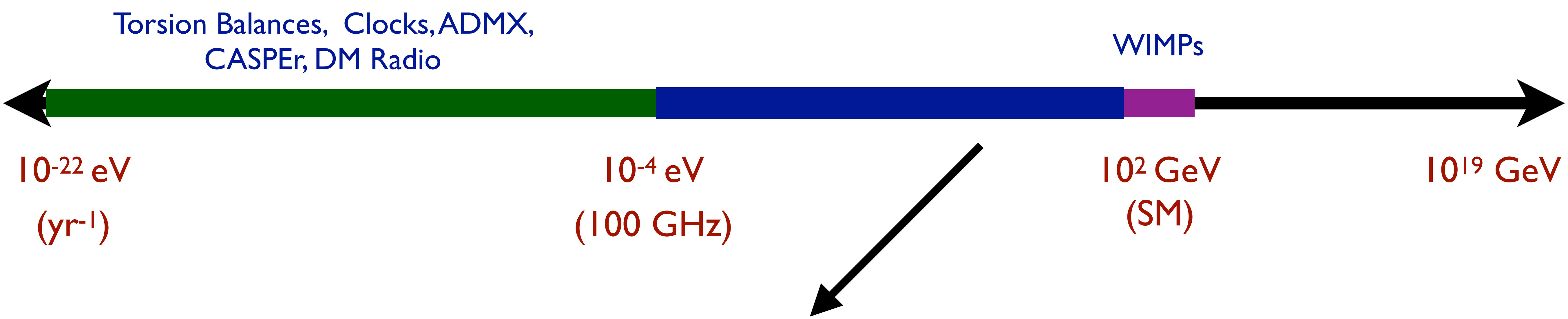

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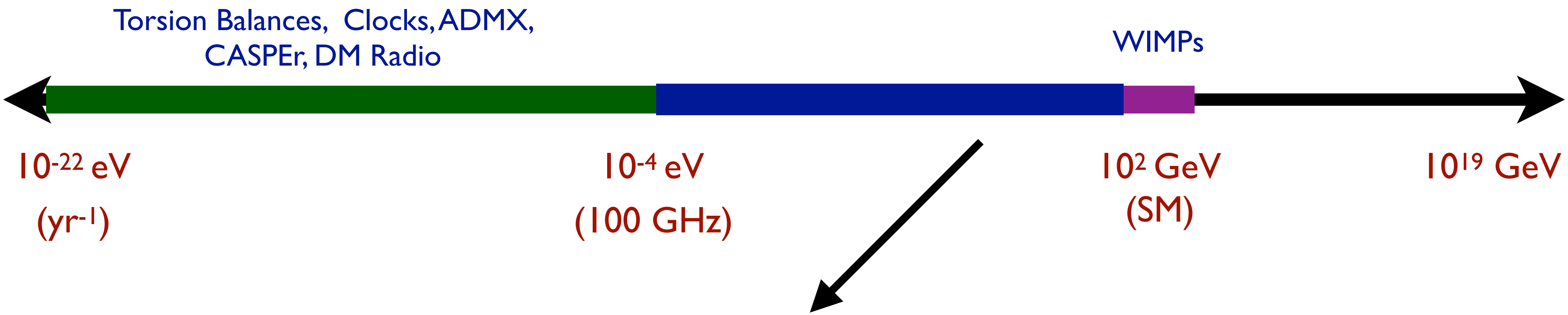

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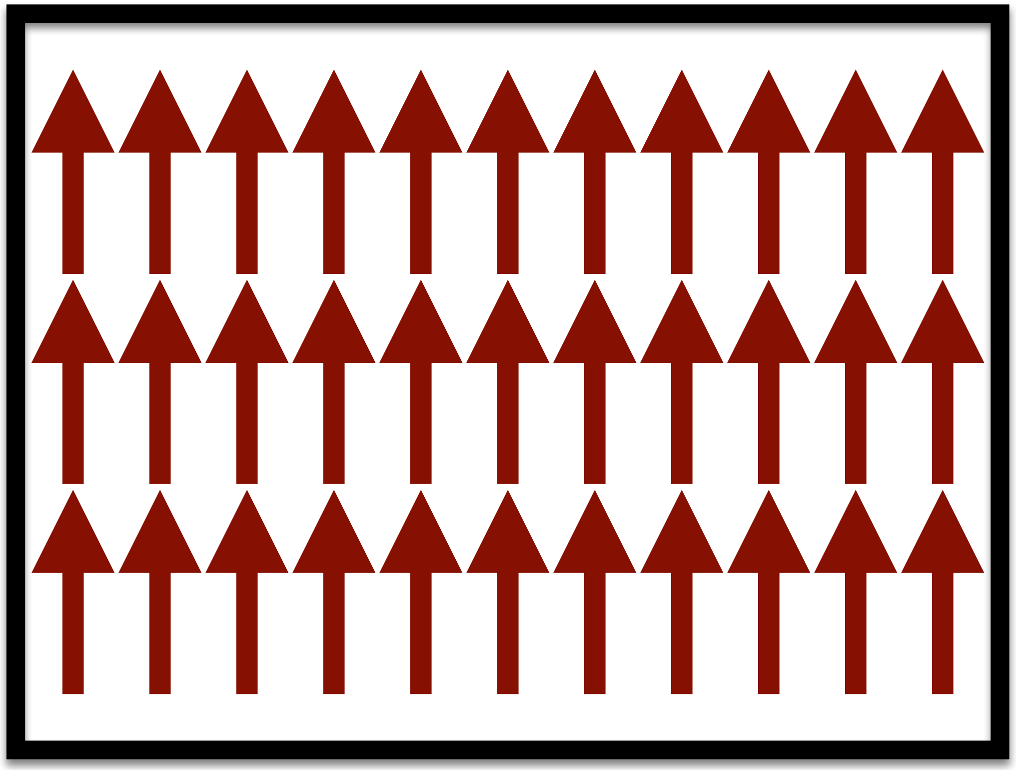
Challenge: Need large target mass. Rare dark matter event. Requires amplifier stability > years

Concept



Consider magnet with all spins aligned

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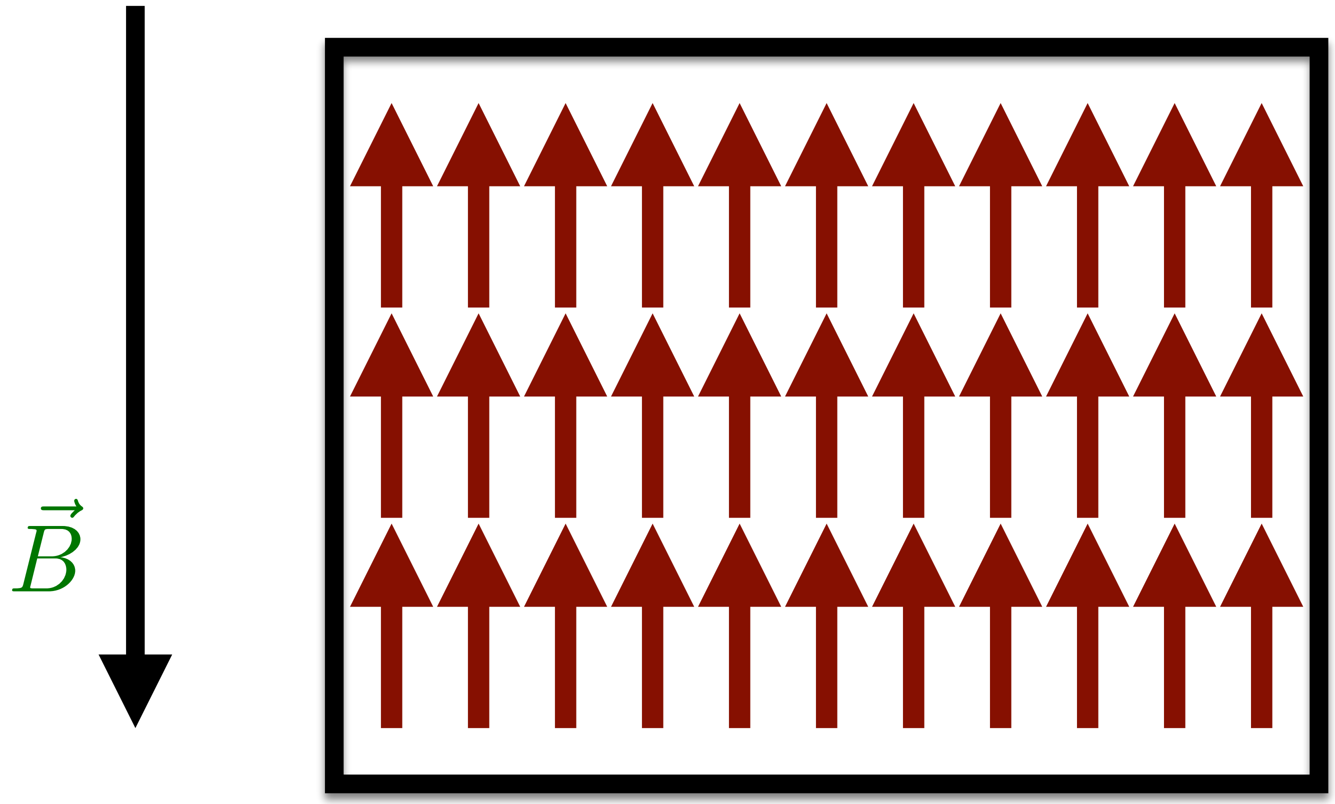

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Spins now in metastable excited state with energy ~ g μ B

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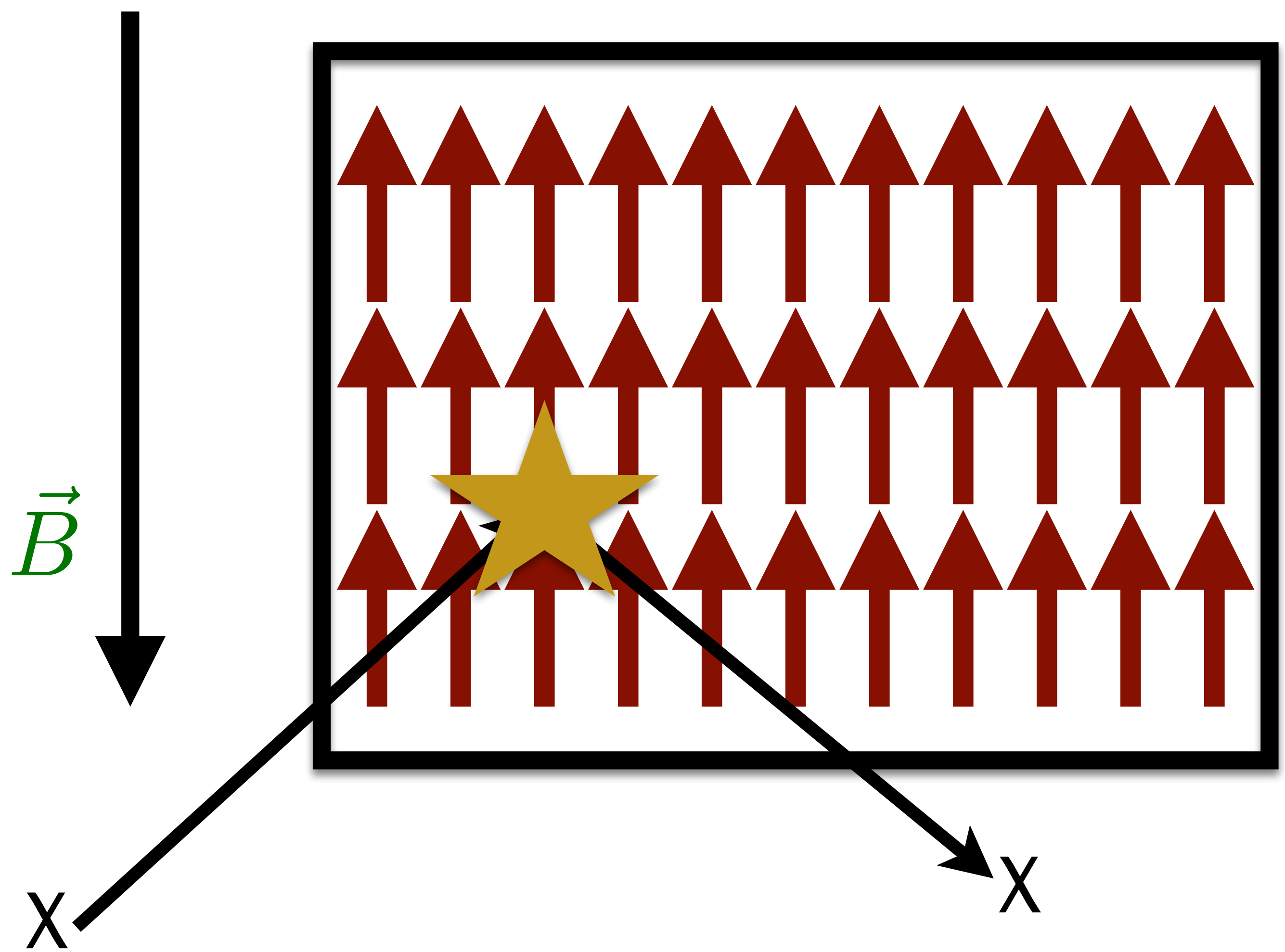

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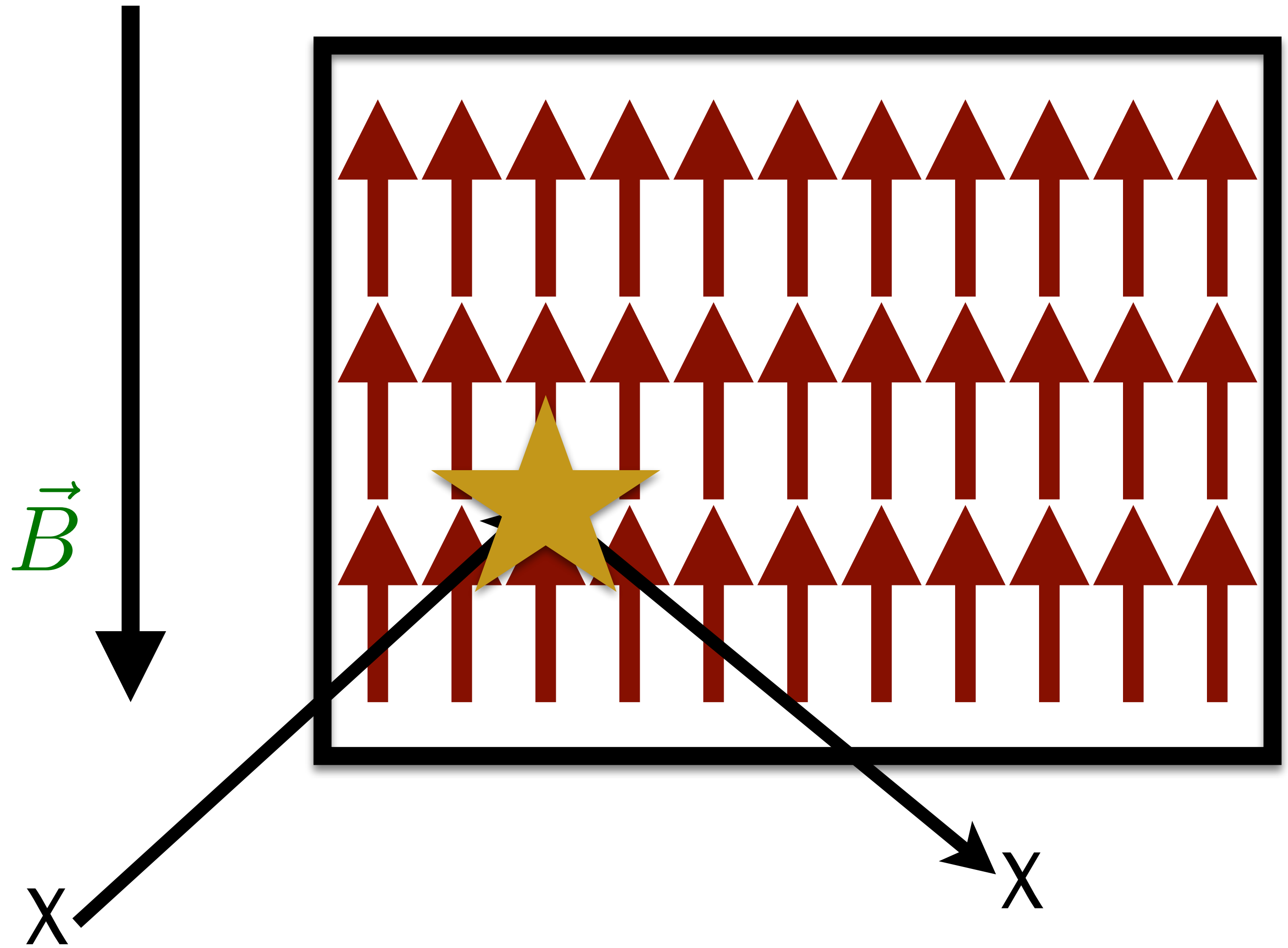

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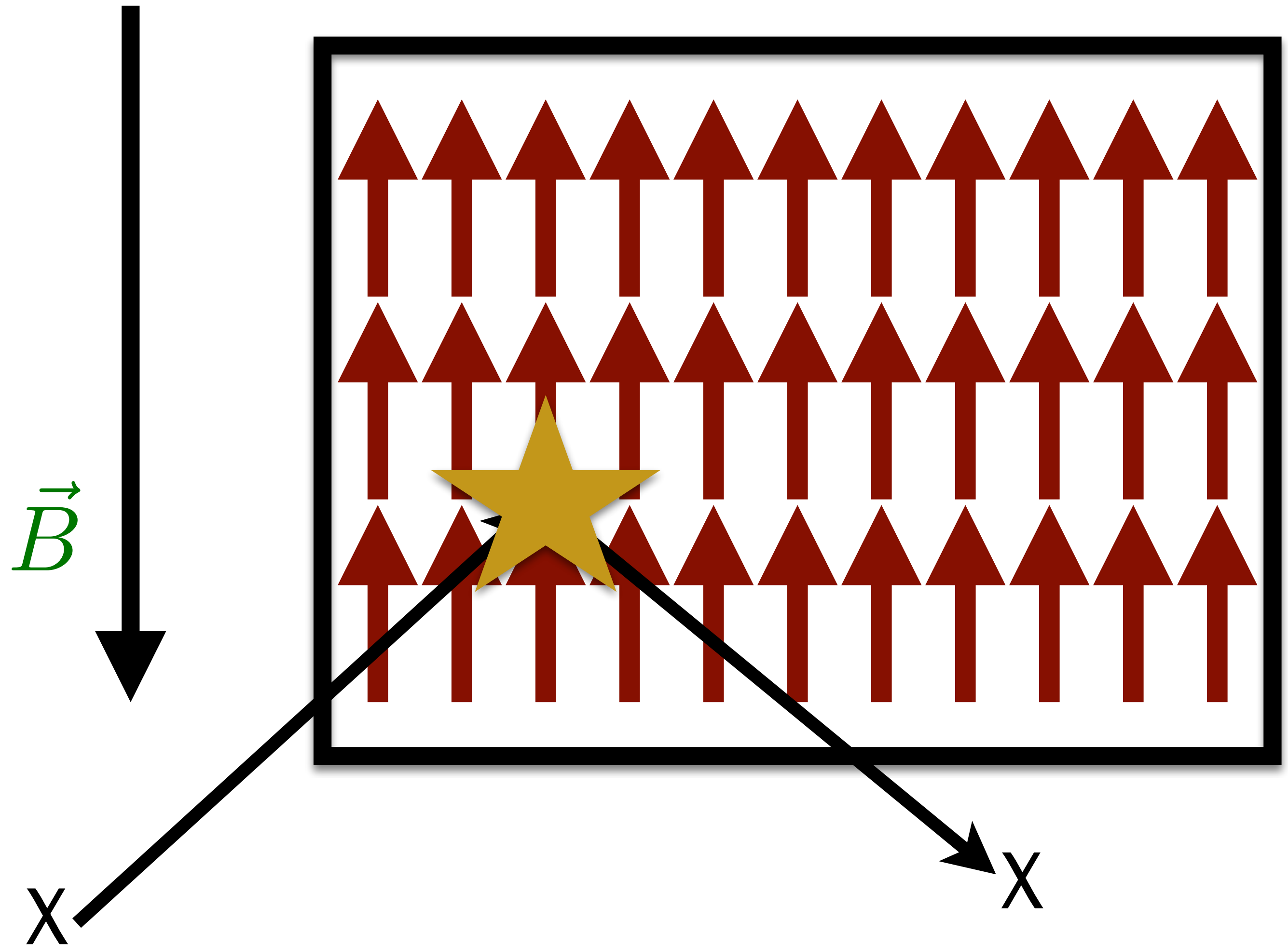

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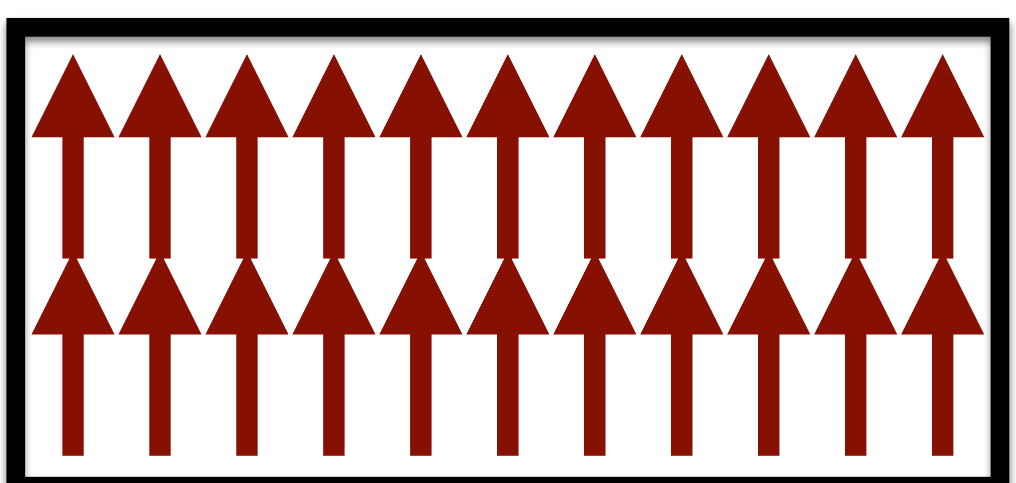

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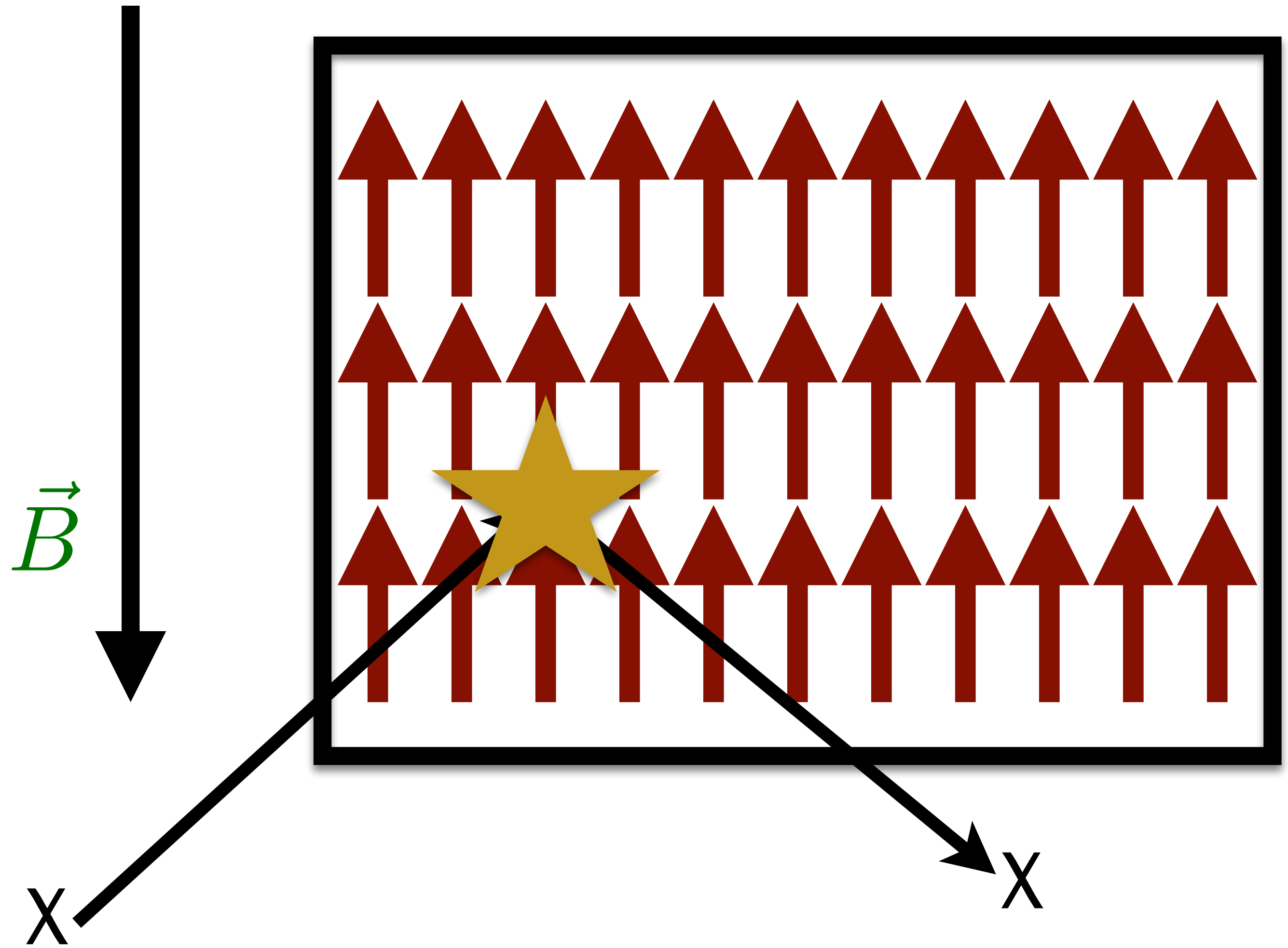

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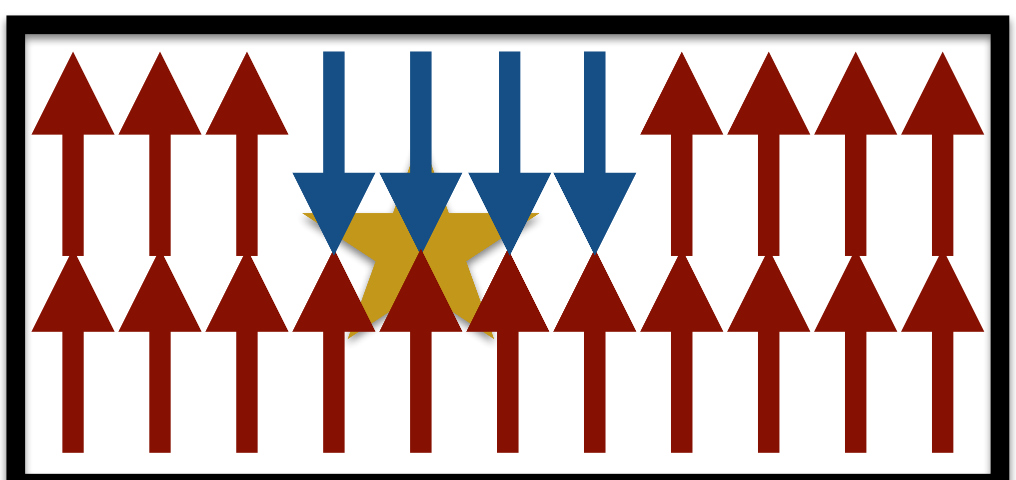

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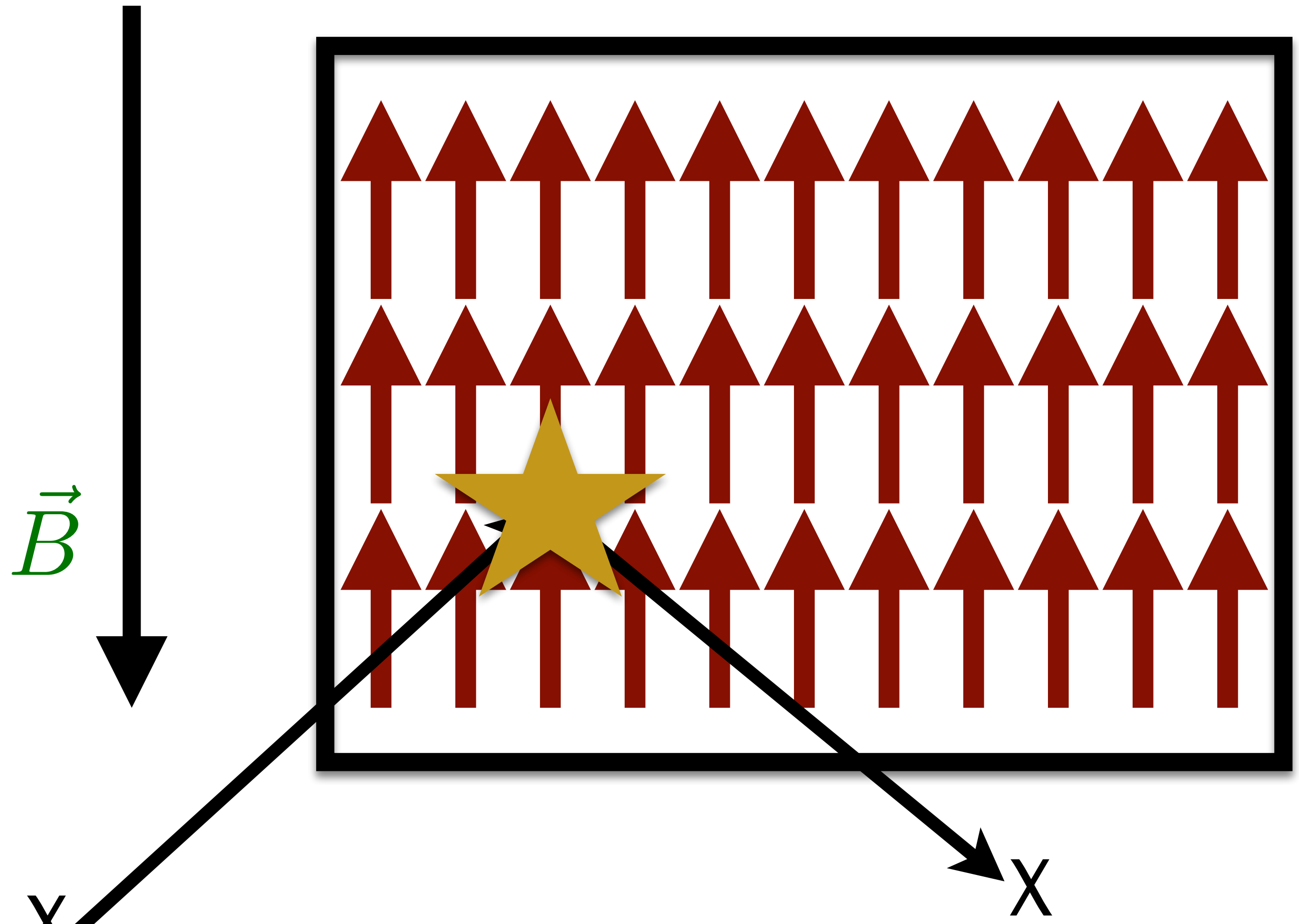

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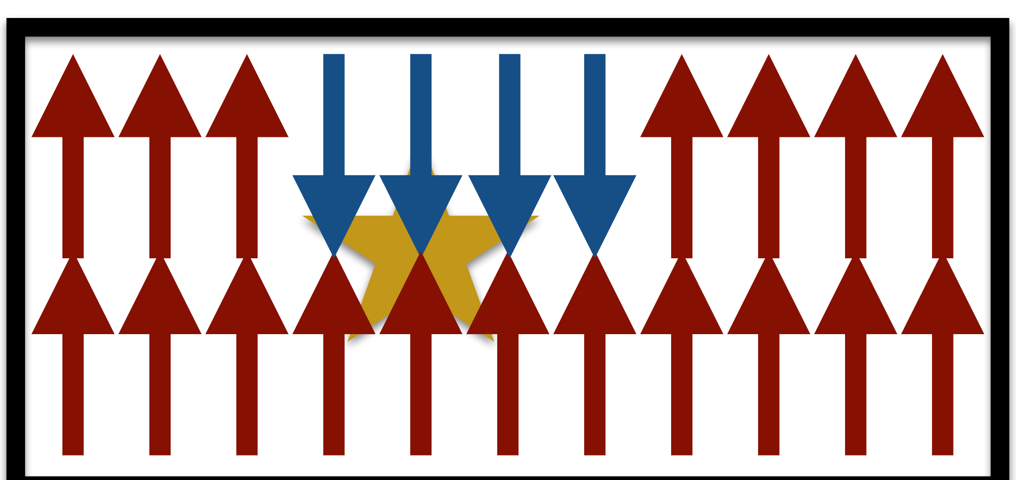

Amplifies deposited energy. Like a bubble chamber. Is this possible? Stability?

Single Molecular Magnets

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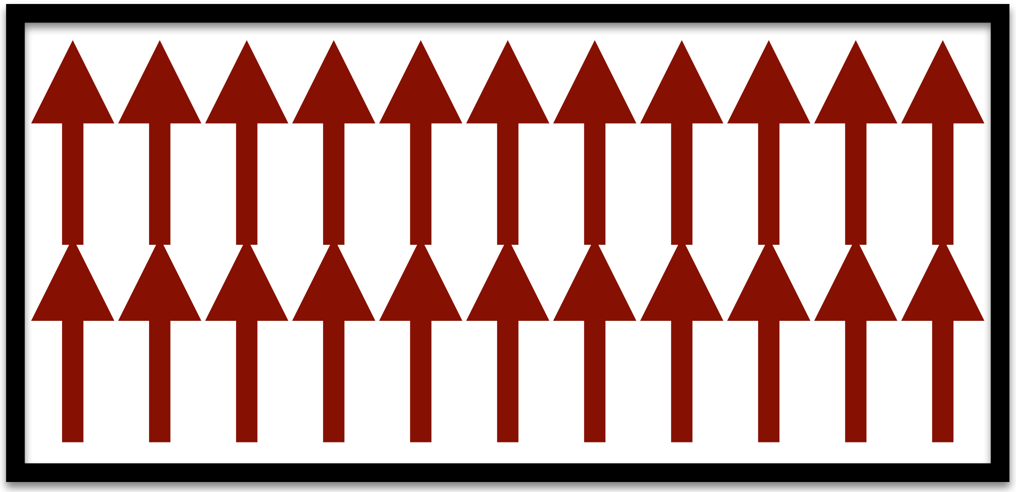

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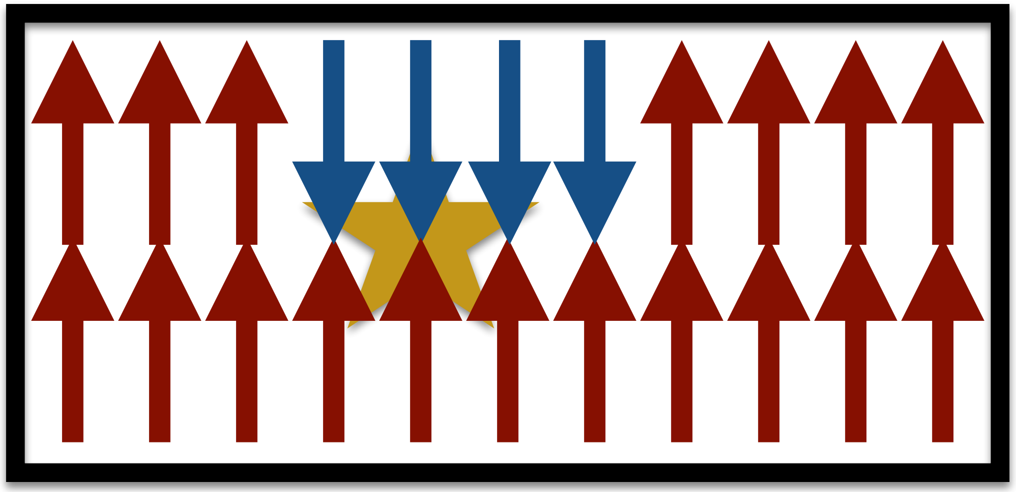

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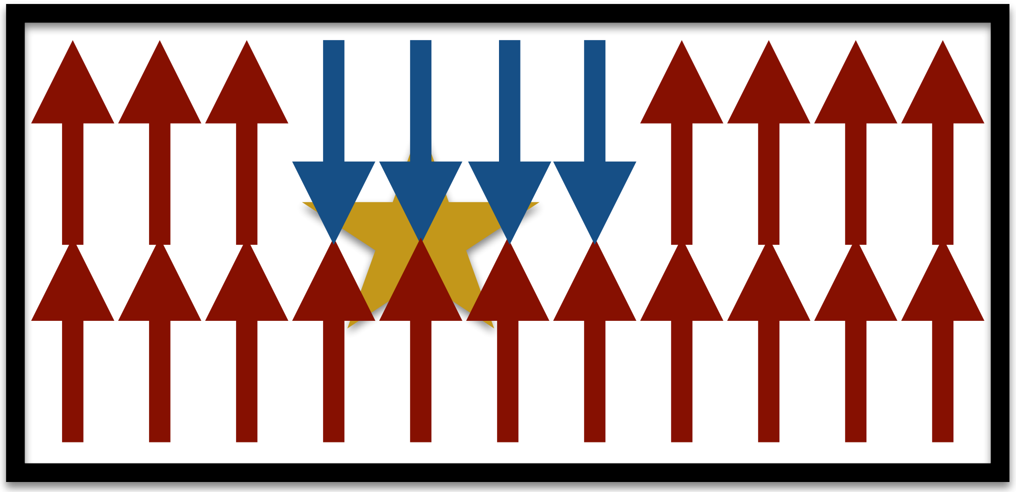

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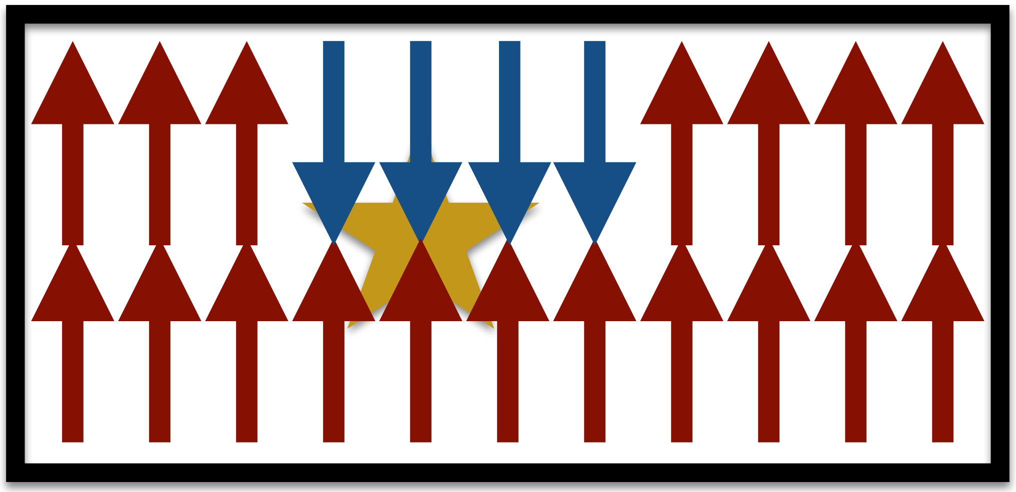

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Need weak spin-spin coupling. But need large density - necessary for heat conduction. Can't use gas.

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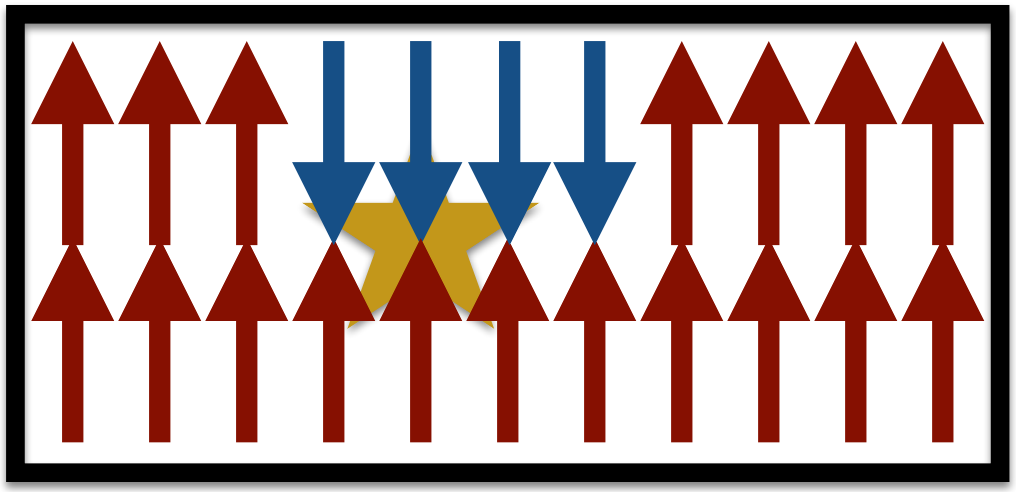

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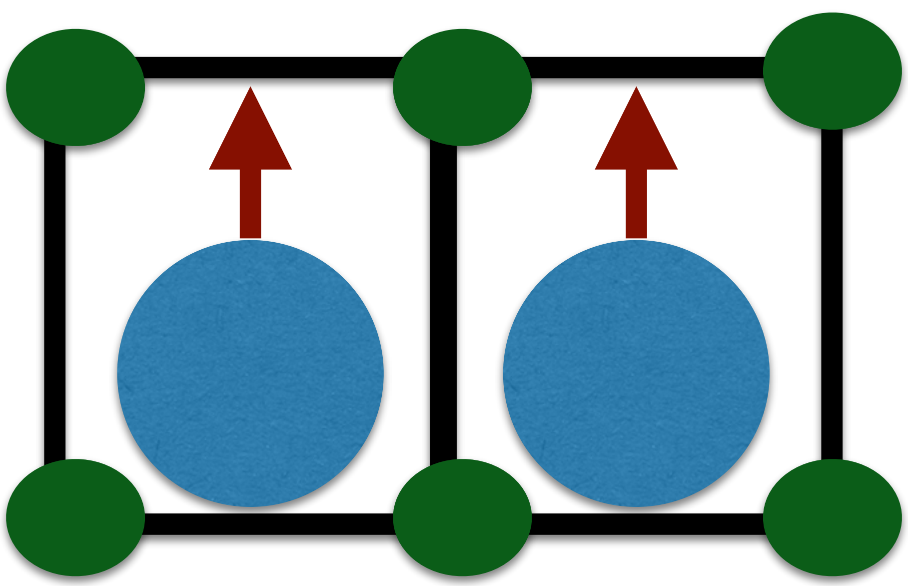

Organo-Metallic complexes.
Central metal complex surrounded by organic material.

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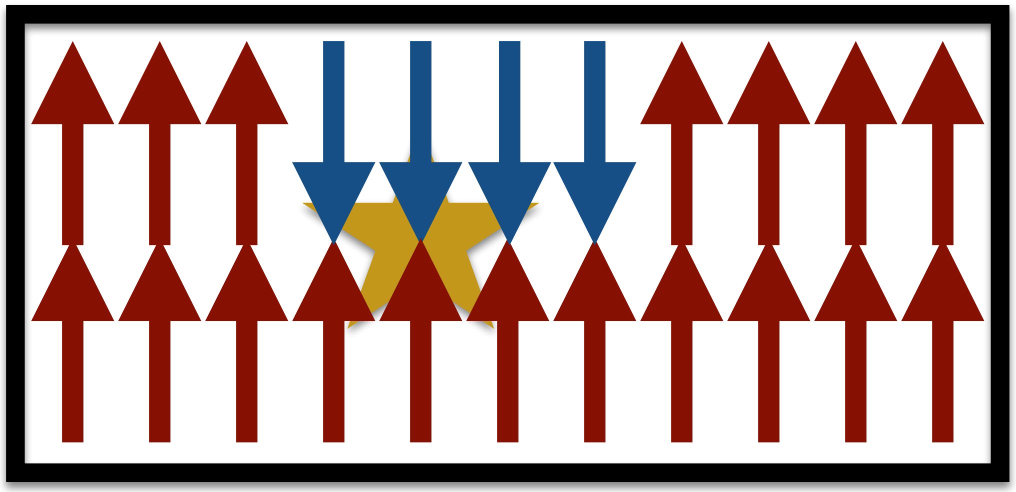

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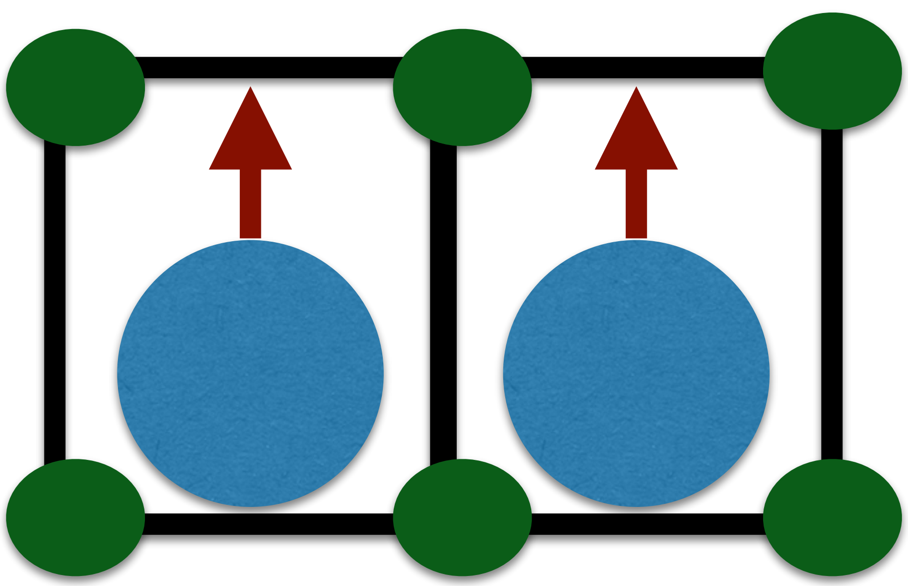

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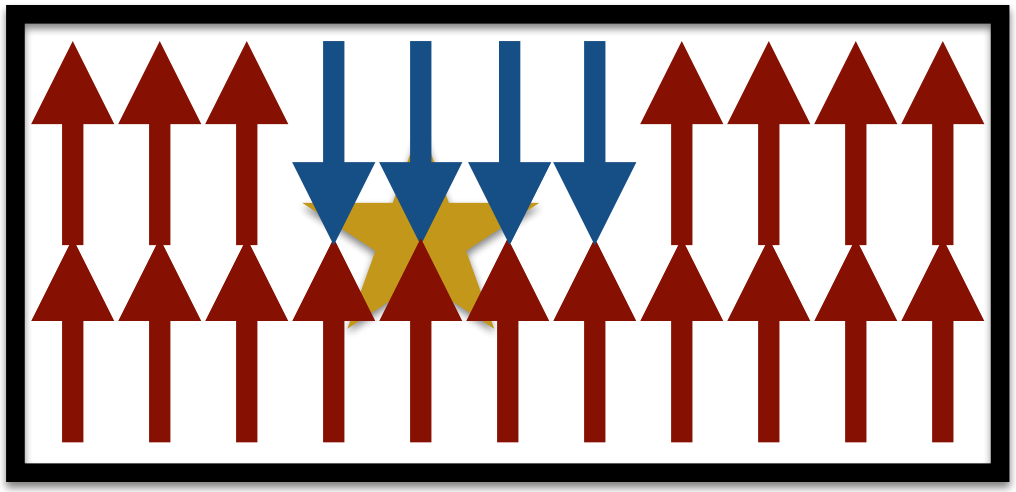

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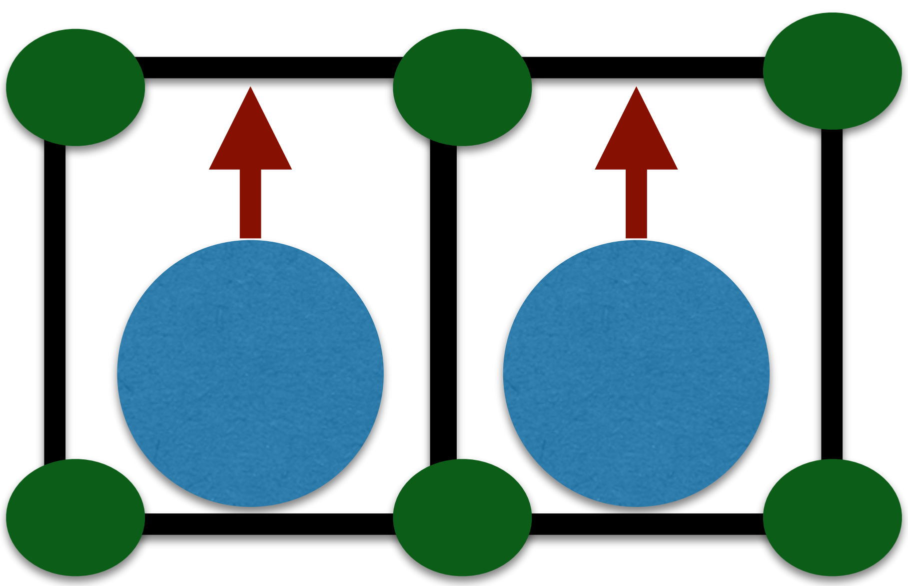

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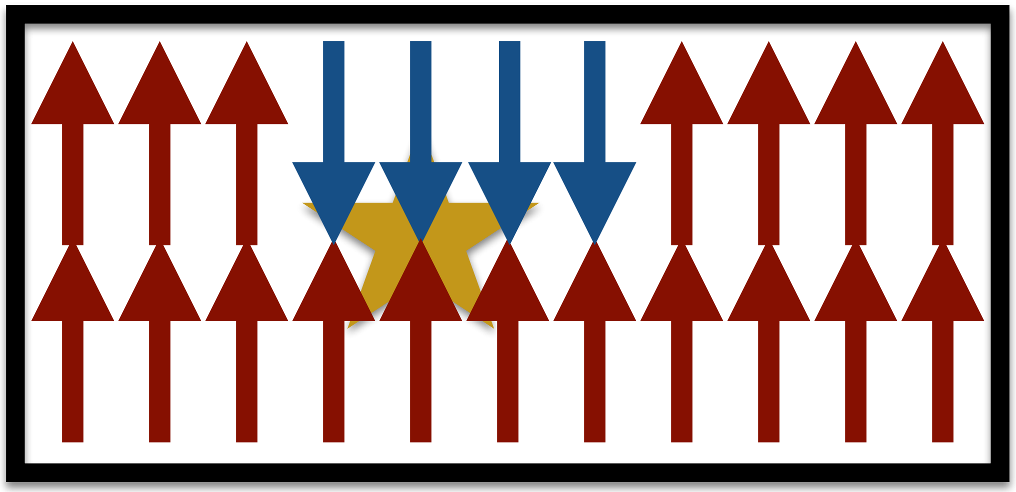

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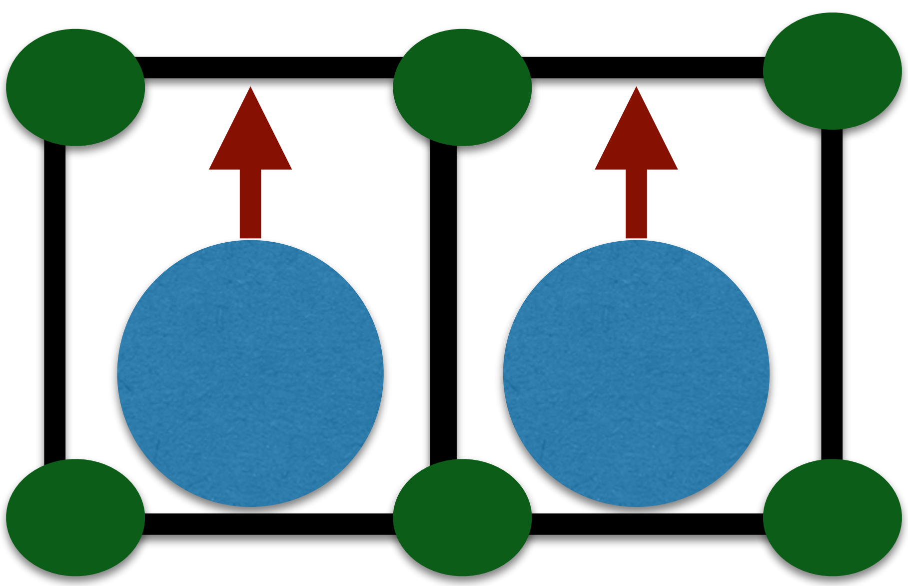

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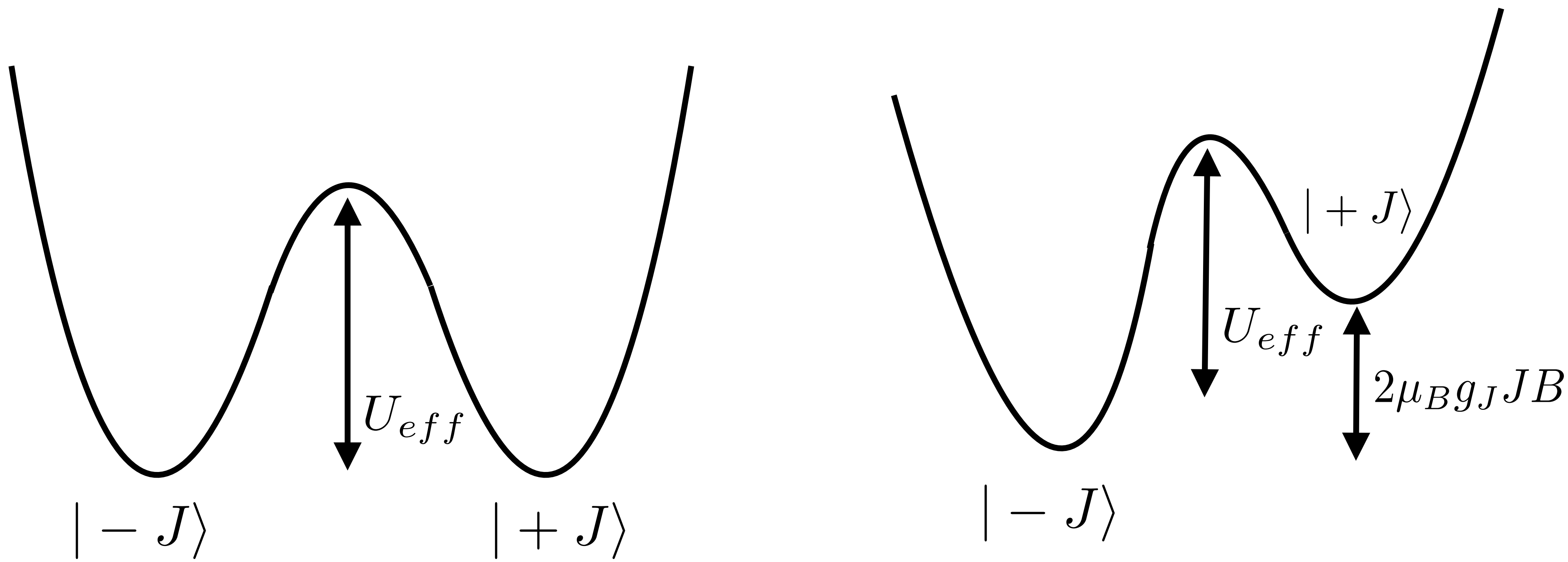
Recently discovered systems. Few 100 known examples. Can make large samples. Magnetic deflagration experimentally observed and well studied in Manganese Acetate complexes

Magnetic Deflagration



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Two states separated by energy barrier.

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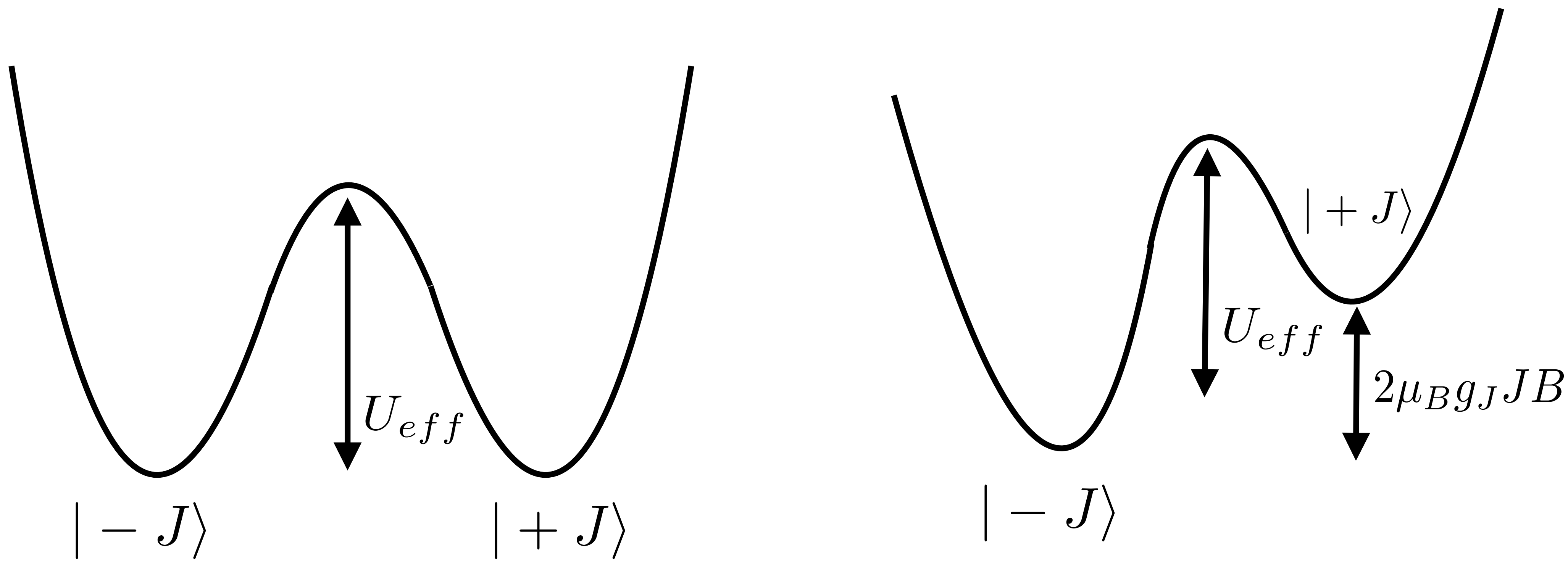

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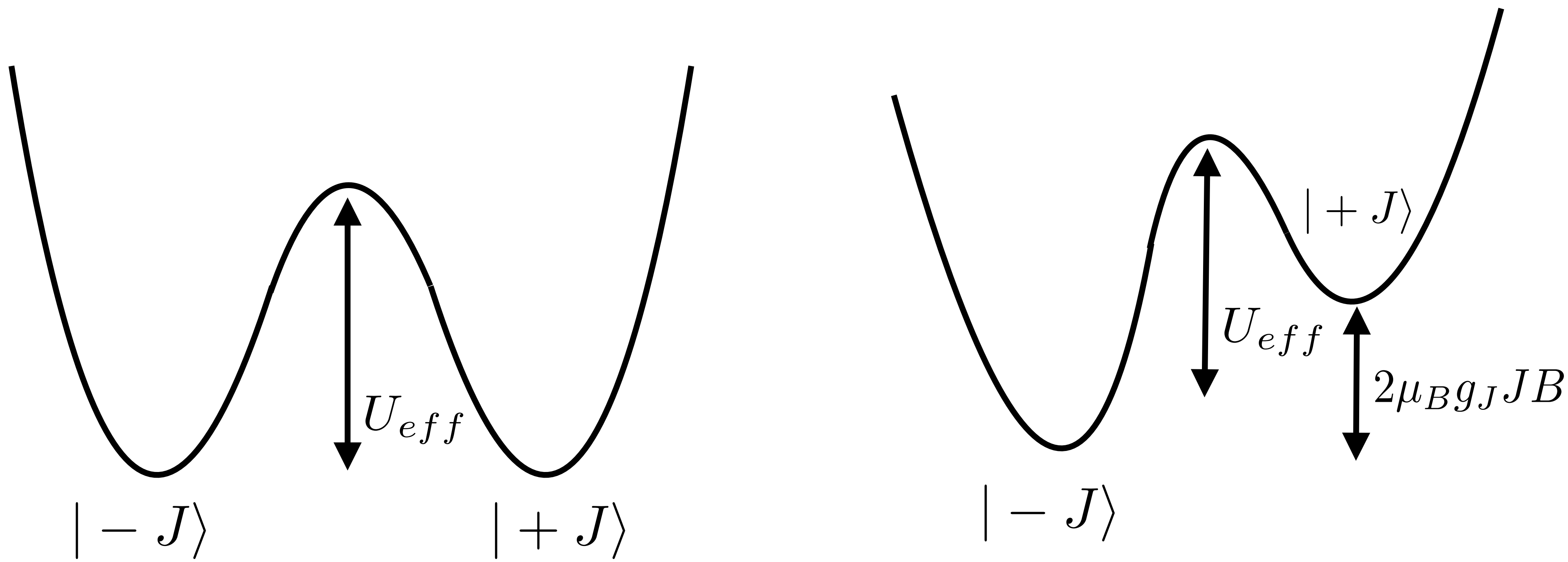

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Ultra-long lived state at low temperature - localized heating rapidly decreases life-time, decay results in more energy release

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Initially heat region of size λ to T

Thermal Diffusion, lowers T

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Known examples with $\tau_0 \sim 10^{-13}$ s, $U_{eff} \sim 70$ K, enabling 0.01 eV thresholds

Detector Stability

High energy (> MeV) background from radio-active decays.

Detect MeV events using conventional means. Actual background at low energy very low - forward scattering of compton events

Problem: MeV events will constantly set off detector. Reset time vs operation time? Big problem for bubble chambers like COUPP

Expected background ~ $1/(m^2\ s)$. Initial detector size ~ $(10\ cm)^3$ (kg mass), 1 background event ~ 100 s

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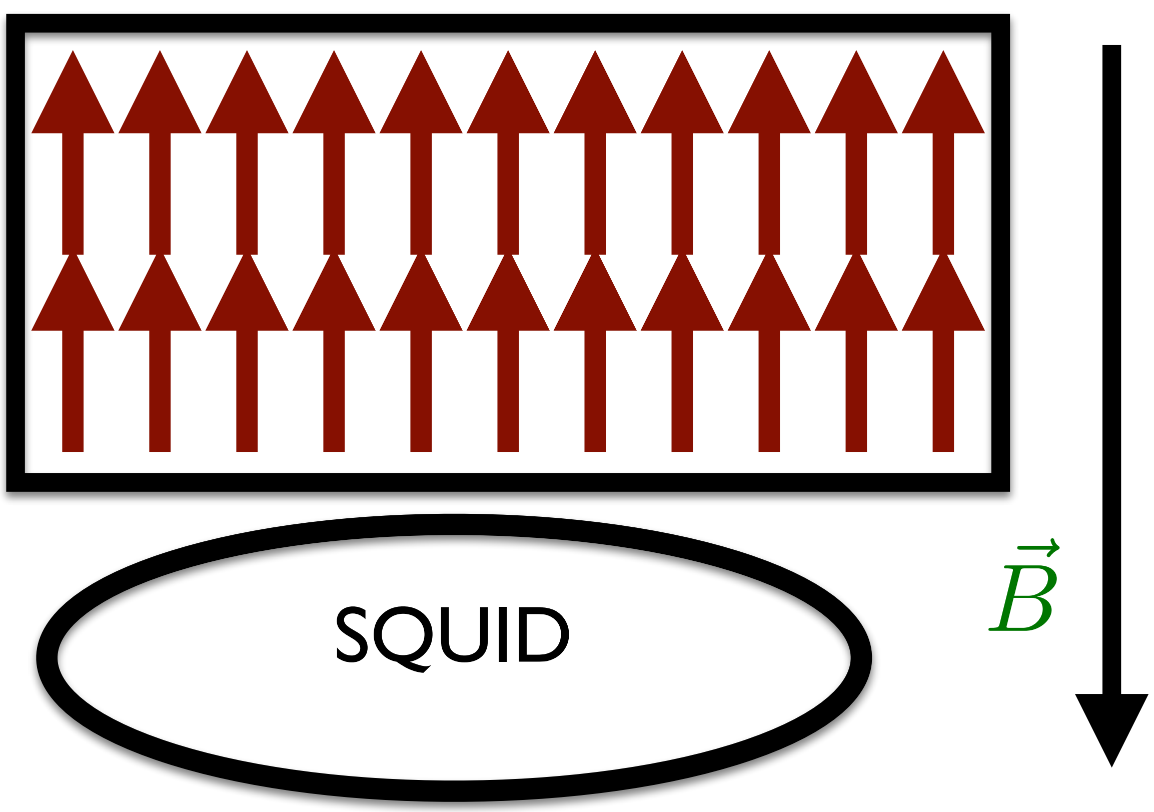

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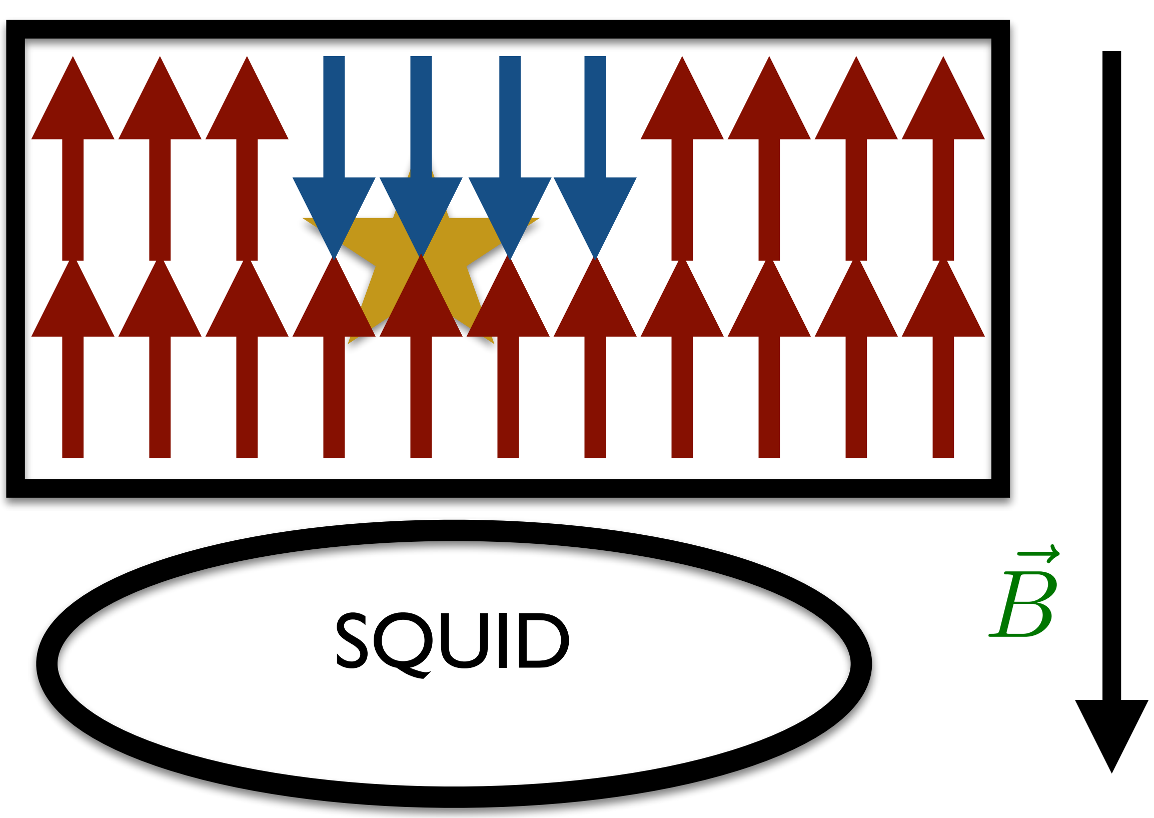

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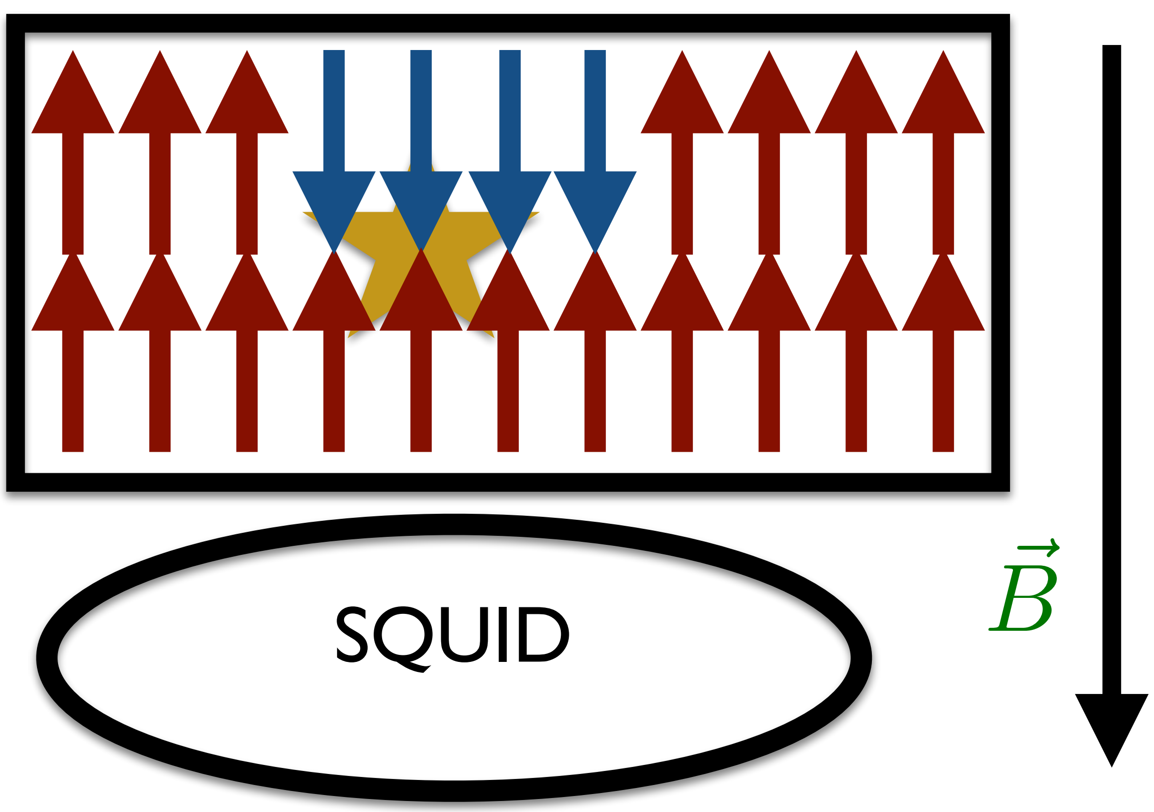

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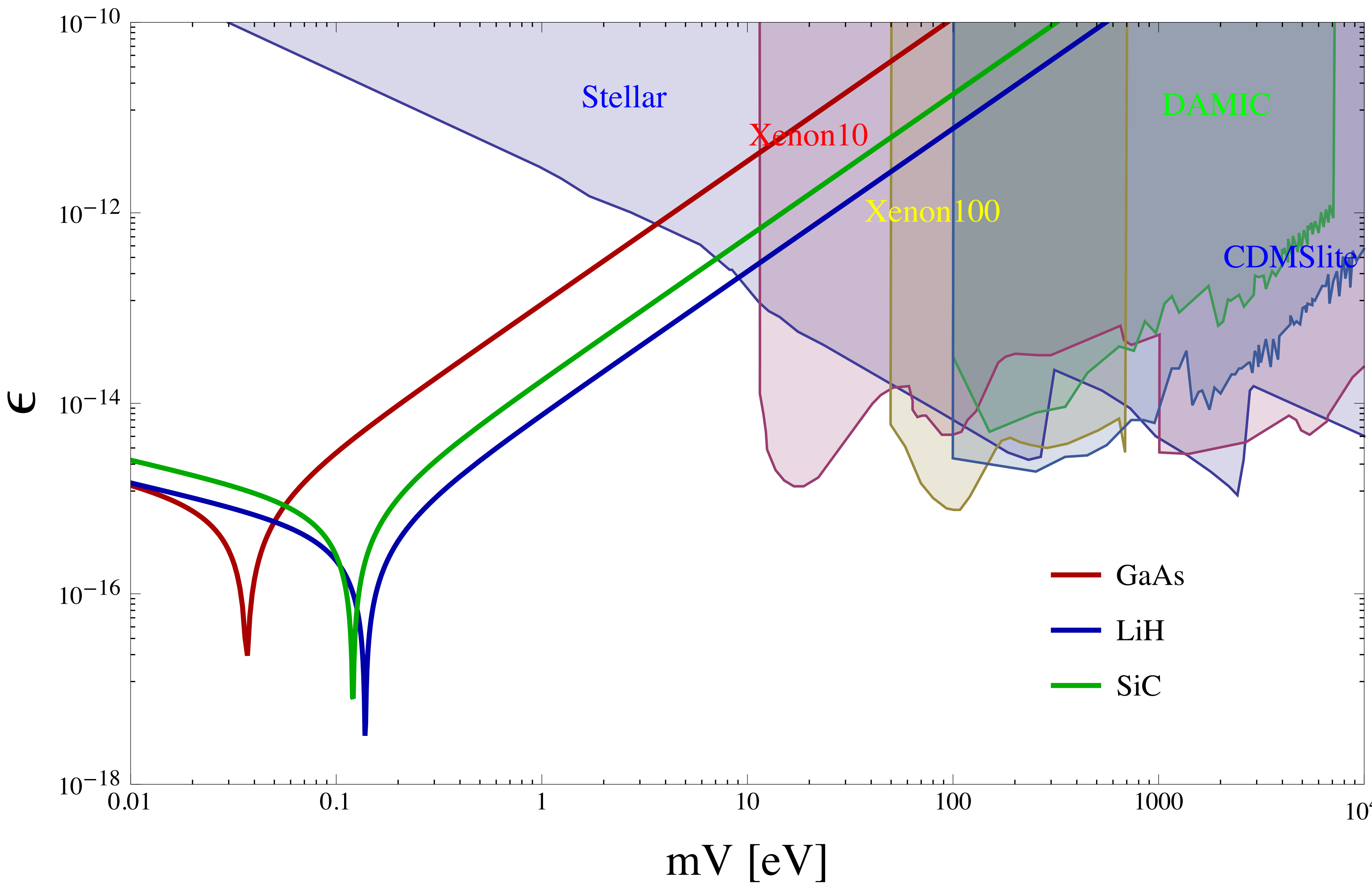
Shut off B, turn off fuel. Deflagration stops. Lose ~ (10 - 100 μm)^3 of volume every 100 s.

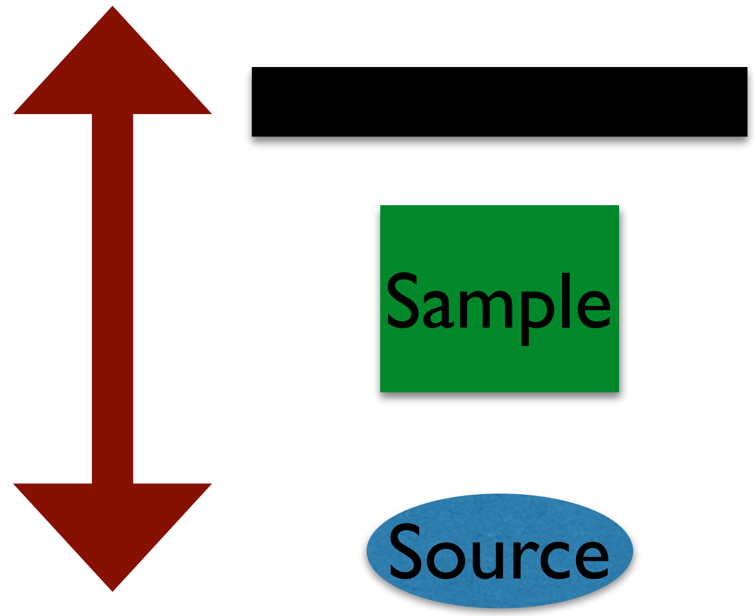
Potential Reach

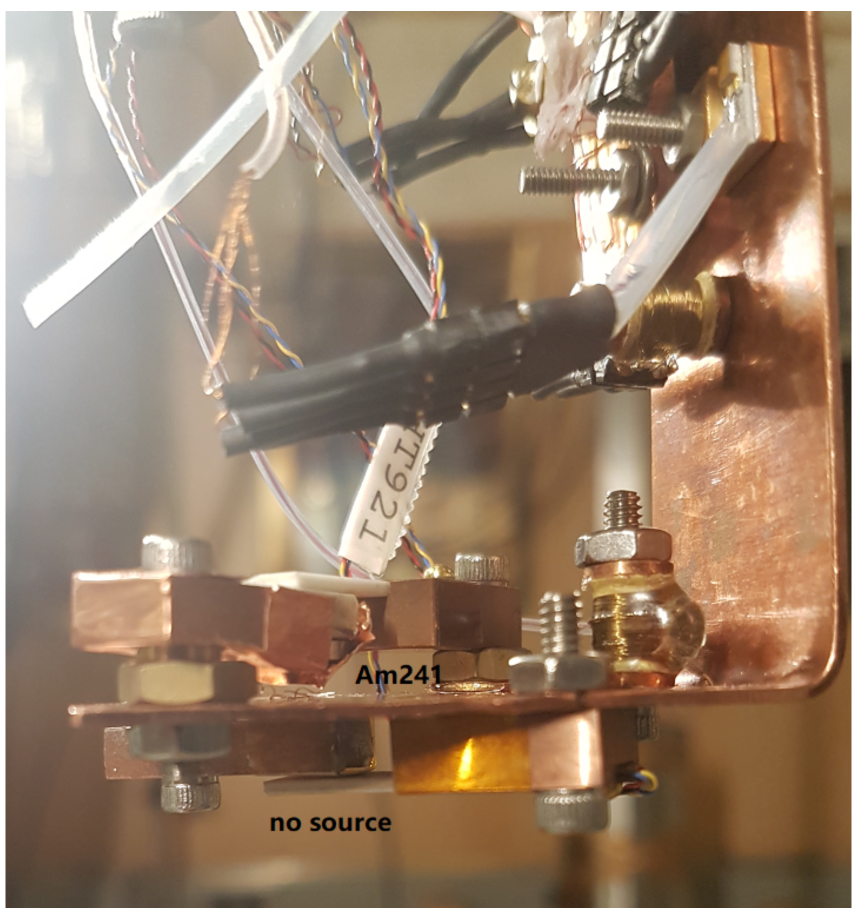
$$\mathcal{L} = -\frac{1}{4}\left(F_{\mu\nu}F^{\mu\nu} + F'_{\mu\nu}F'^{\mu\nu}\right) + \frac{1}{2}m^2_{\gamma'}A'_\mu A'^\mu - eJ^\mu_{EM}\left(A_\mu + \varepsilon\, A'_\mu\right)$$



Absorption obtained from photoabsorption. Exposure of 1 kg-year

Trial using Mn-Ac





Two sets of Mn12-Ac and Hall sensors

One with μCi Am 241 α source
One without source

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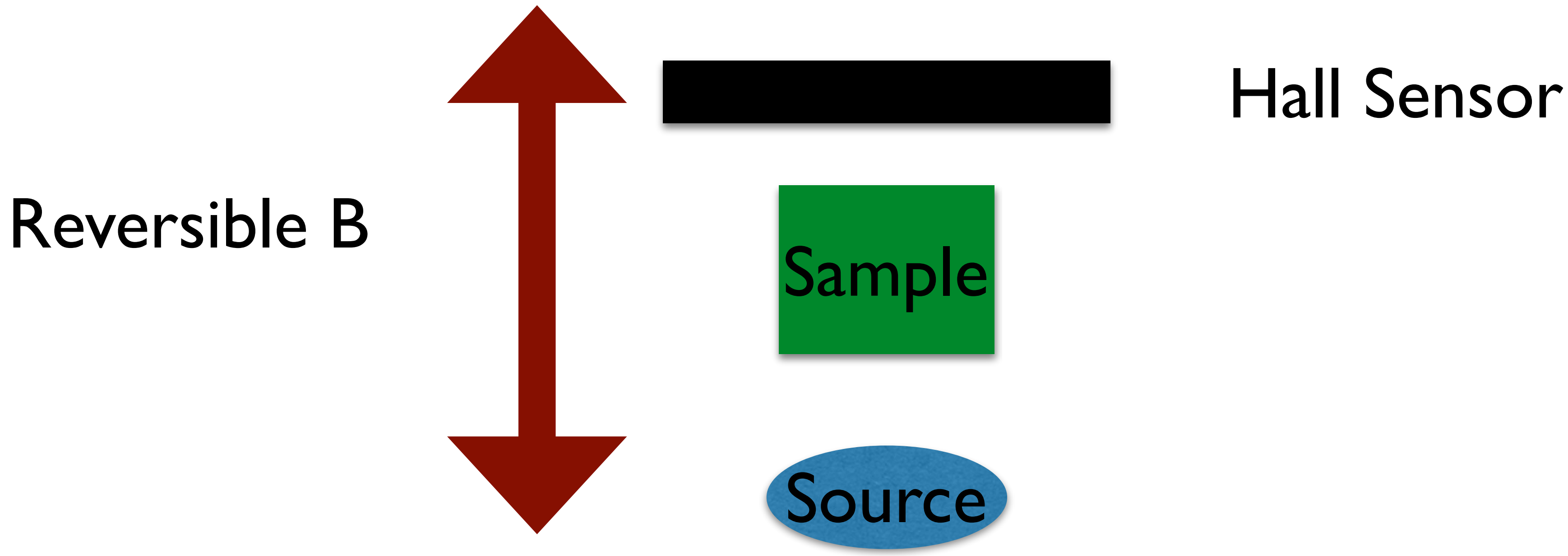

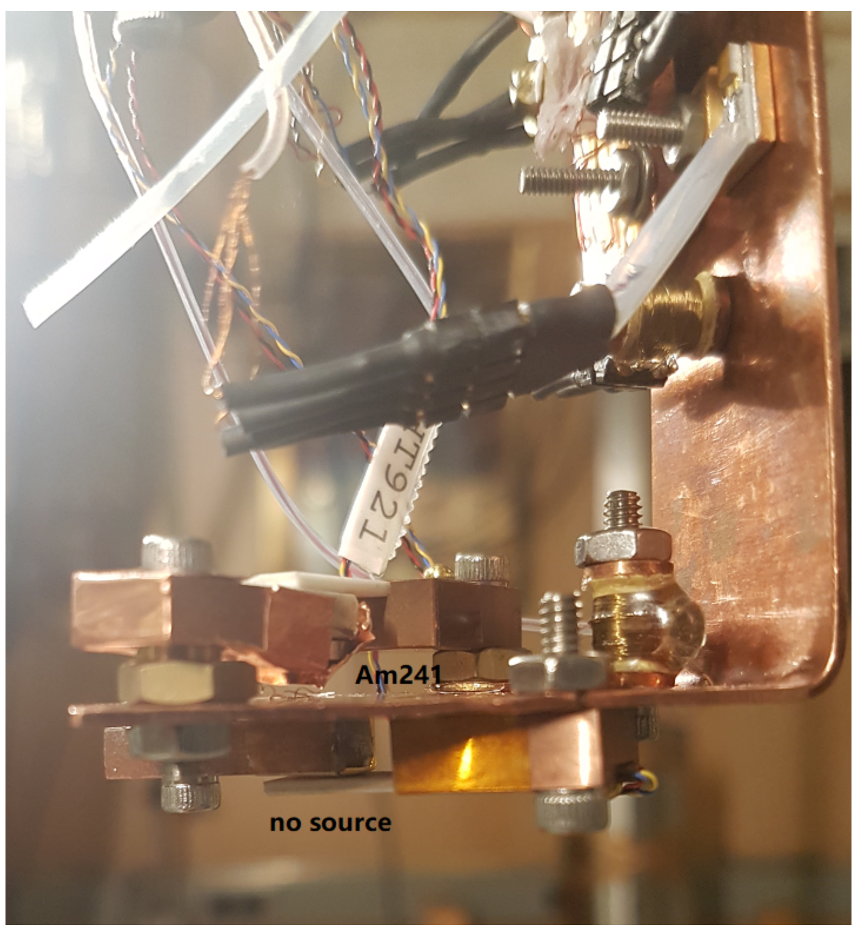

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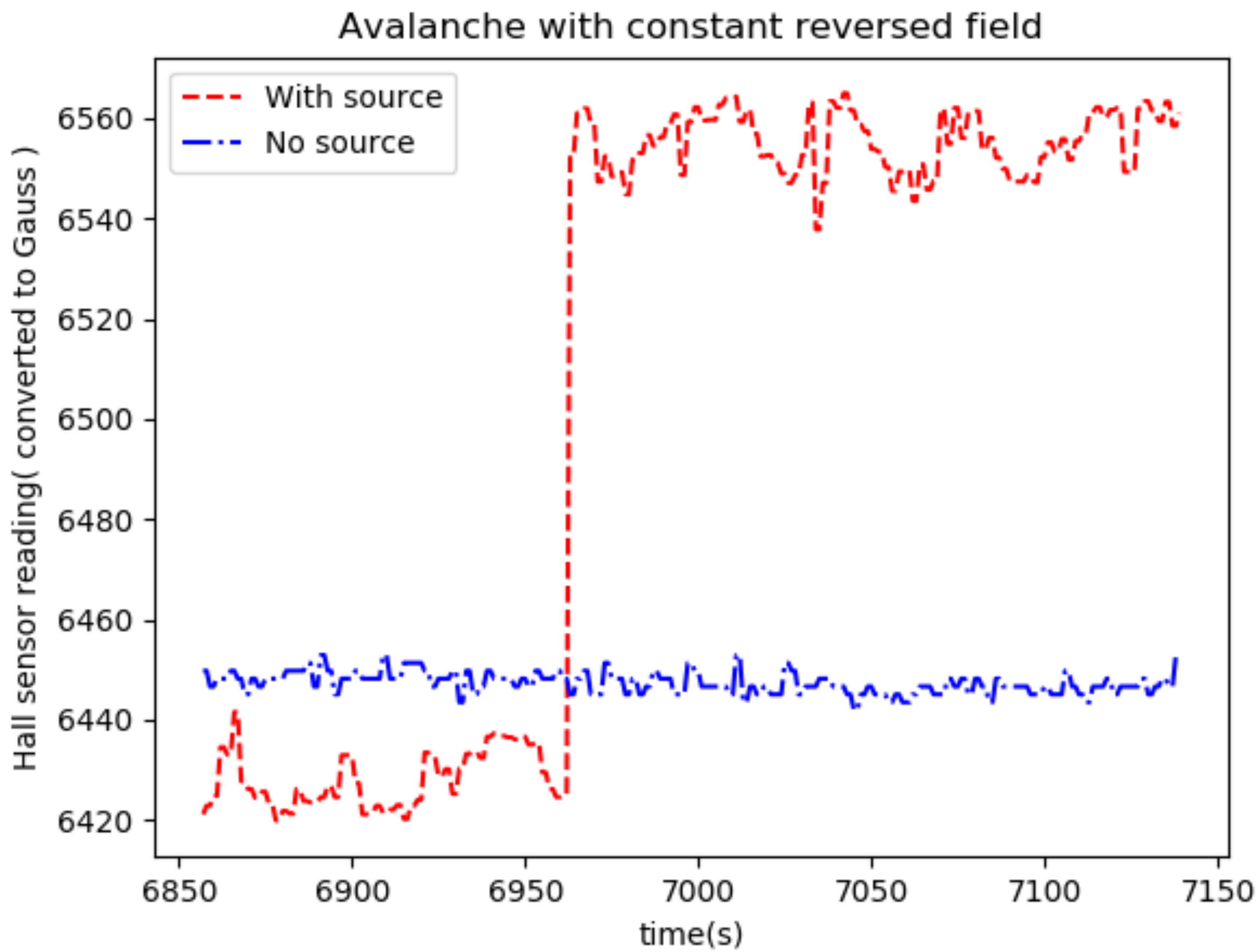
Metastability? Deflagration?

Results



Avalanche only observed with source

Mn12-Ac has high threshold (~ few MeV) - using new materials now

Conclusions

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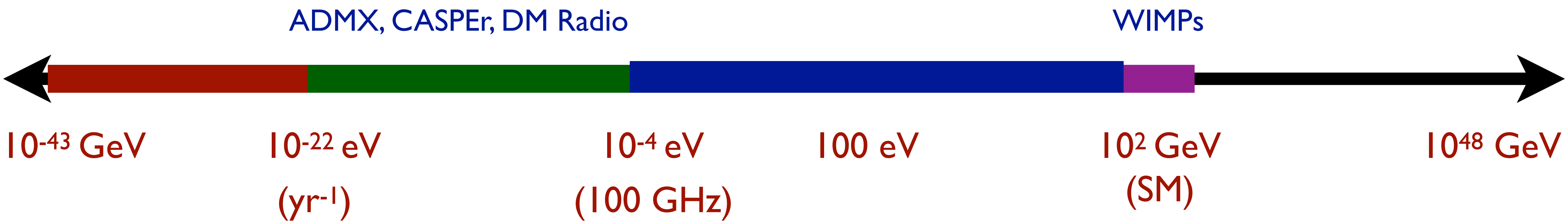

Poor observational constraints on dark matter

New ideas needed to probe dark matter between 10^{-4} eV - GeV

Single Molecular Magnets offer unique opportunity for amplifiers
in this range with suitable stability

Promising initial results with Mn12-ac
Stay tuned for tests with other compounds