INT Workshop INT-17-69W • October 23 - 27, 2017
Neutron Oscillations: Appearance, Disappearance, and Baryogenesis

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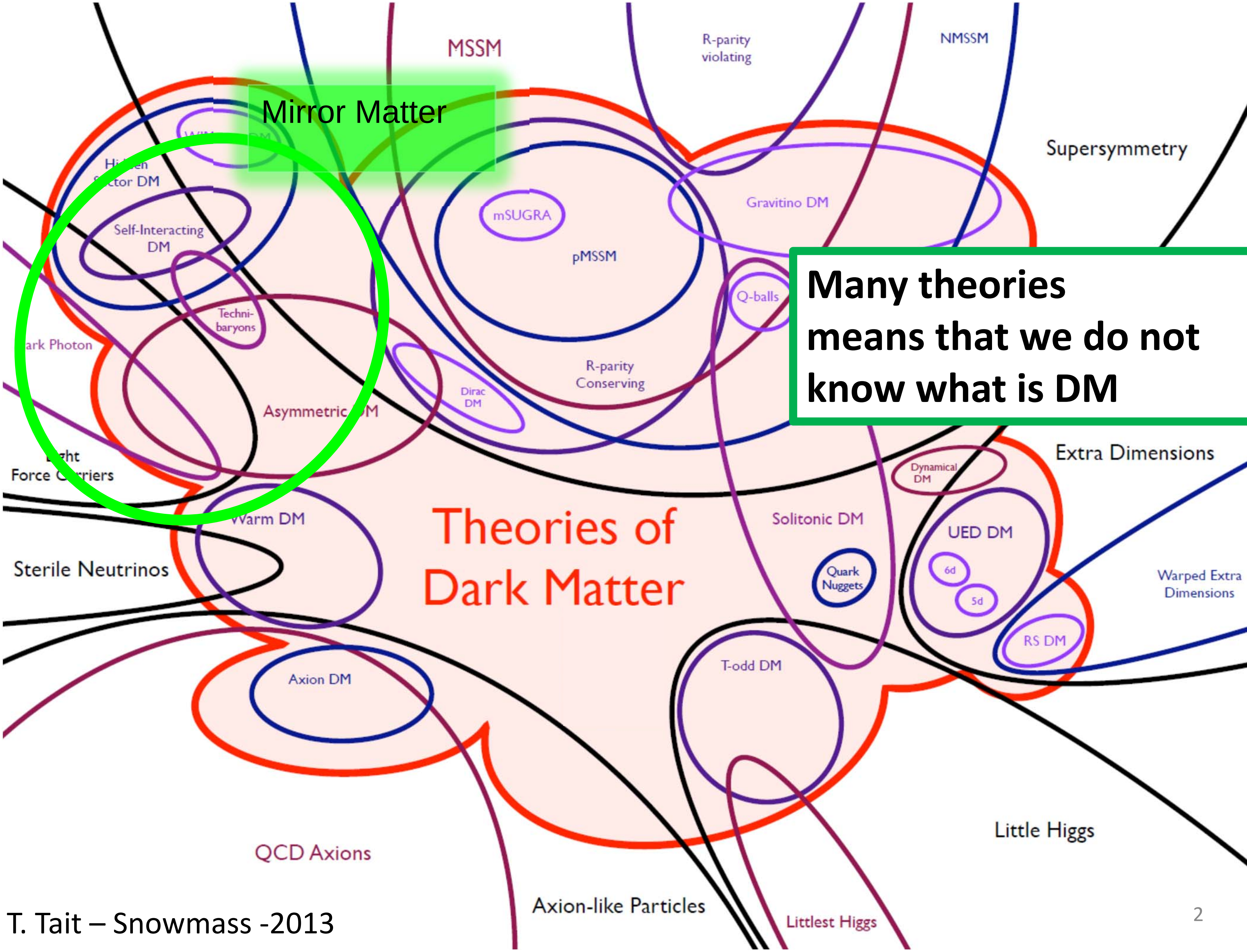
$n - n'$ Oscillations as a Portal to Mirror World

Glossary:
MM – Mirror Matter
DM – Dark Matter
OM – Ordinary Matter



Many theories means that we do not know what is DM

T. Tait – Snowmass -2013

How the concept of Mirror Matter can add to observability of Dark Matter?

via transformation of neutral components:

- $n \rightarrow n'$ transformations might lead to observable neutron disappearance and neutron regeneration effects that can be influenced by laboratory magnetic field $\boldsymbol{B}$.

- Neutron lifetime measurements and reflection of UCN from the walls might be sensitive to $n \leftrightarrow n'$ transformations.

- Finding the resonance vs magnitude and direction of $\boldsymbol{B}$ might be an observation of the presence of mirror magnetic field $\boldsymbol{B}'$ - mirror photon, another actor of Mirror World.

via direct detection of MM:

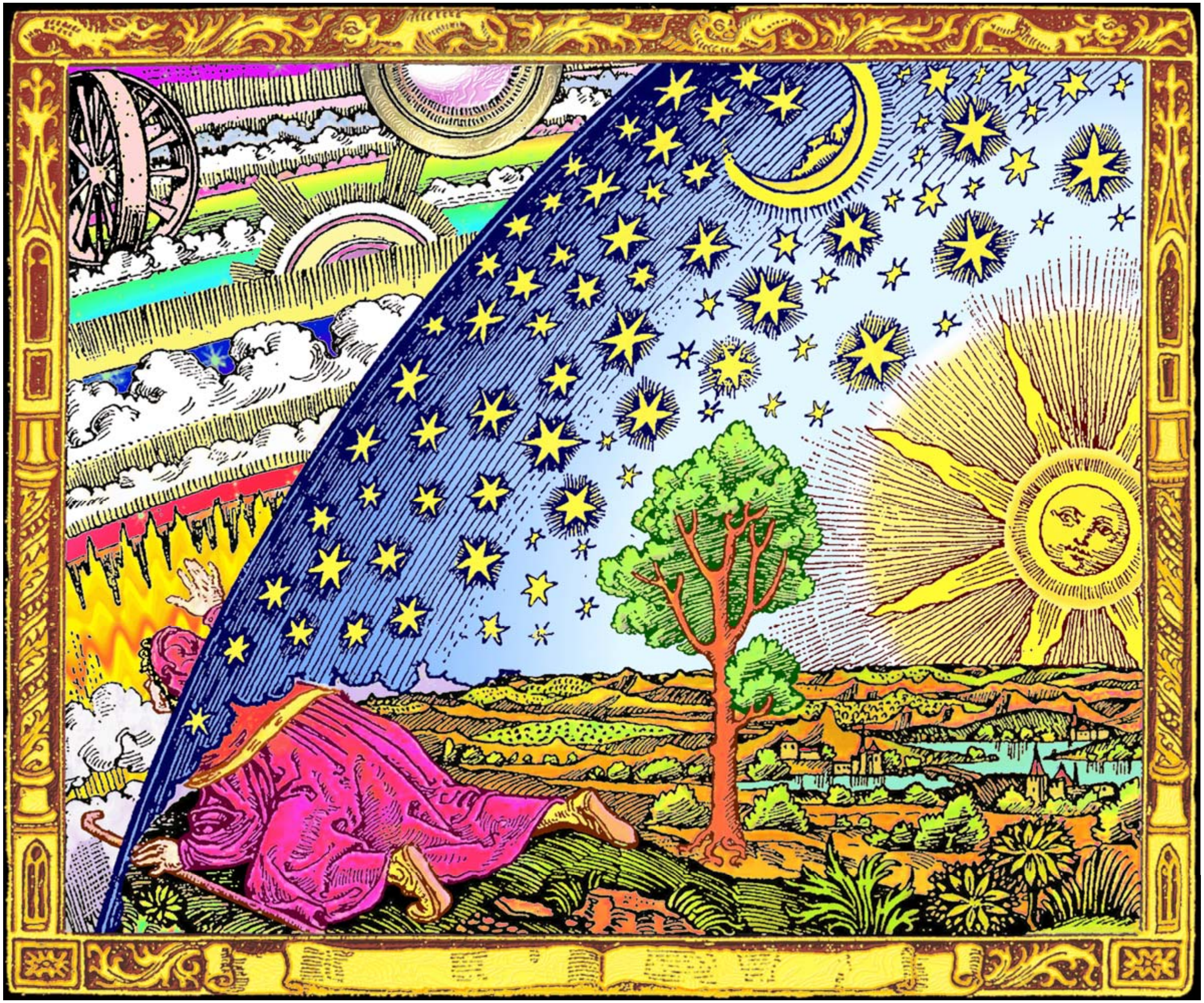
- If MM is exact copy of OM in a sense that SM'=SM, and it is more abundant than OM and "colder" than OM, its cosmological evolution might be different.

- From the side that SM=SM' the microscopic properties of MM are well known, but phenomenology of co-existence of MM near OM can be multi-faceted and for obvious reason difficult for exploration and comprehension.

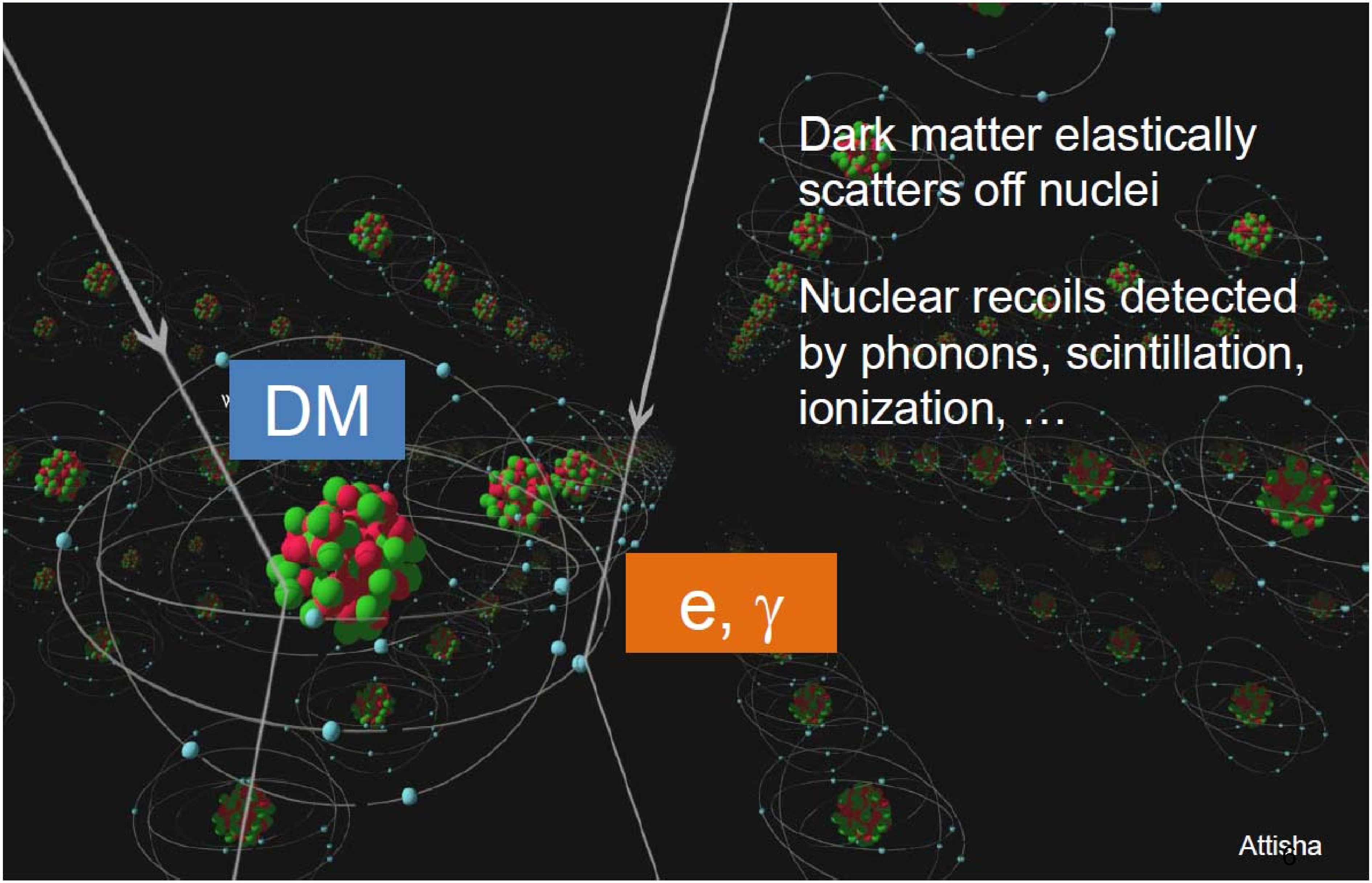
- To be considered: abundance (mirror He > mirror H); most of the MM in the universe is in form of H' and He' gas; initial separation of MM and OM components; MM stellar evolution; mixing one component with another; accumulation one component inside another; mirror magnetic fields; abundance of MM in Milky Way galaxy, current population of MM in the vicinity of Solar system…

Camille Flammarion's engraving 1888

in modern color redrawing

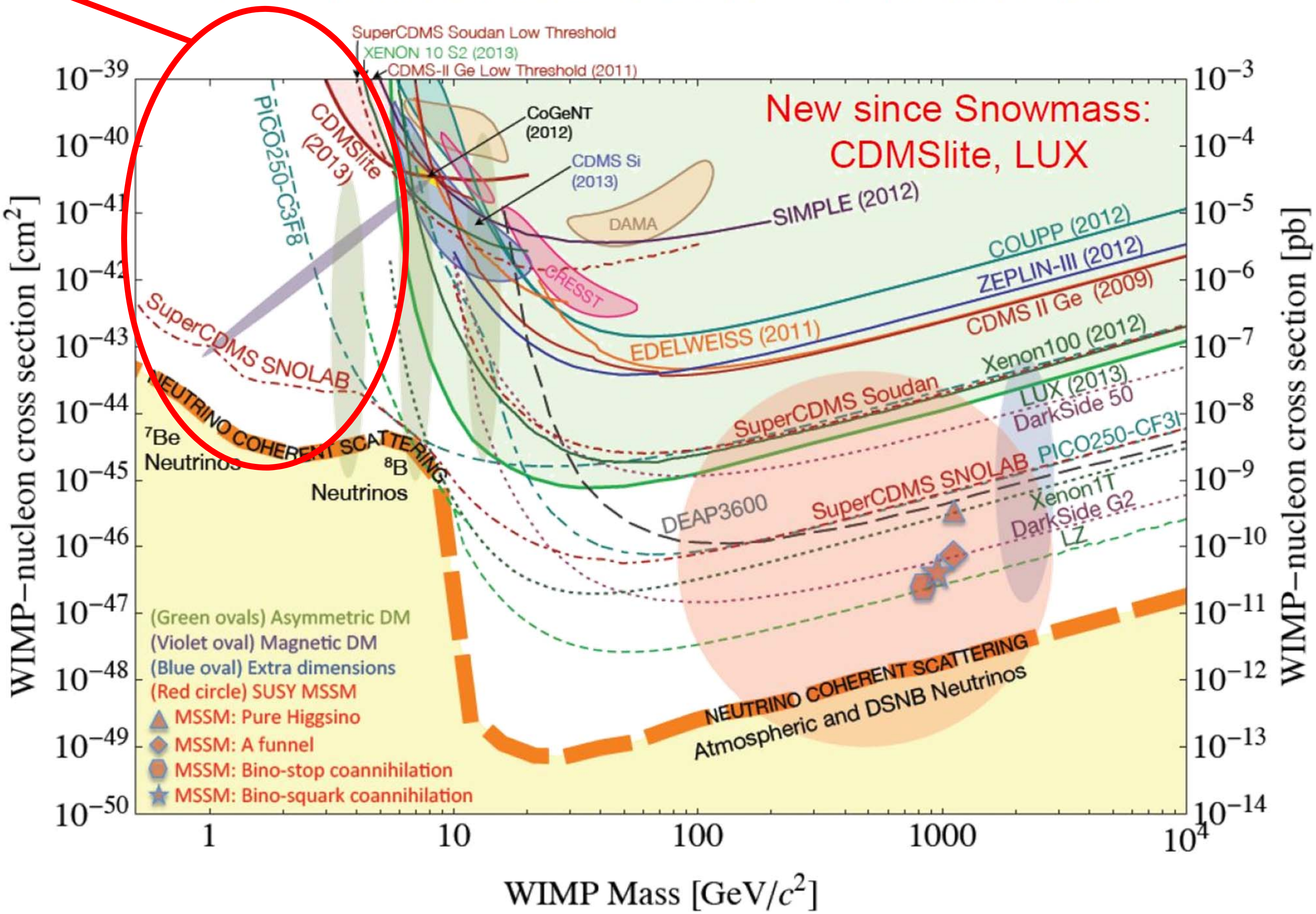


DIRECT DETECTION



Not explored

Dark Matter Direct Detection: Current and Future



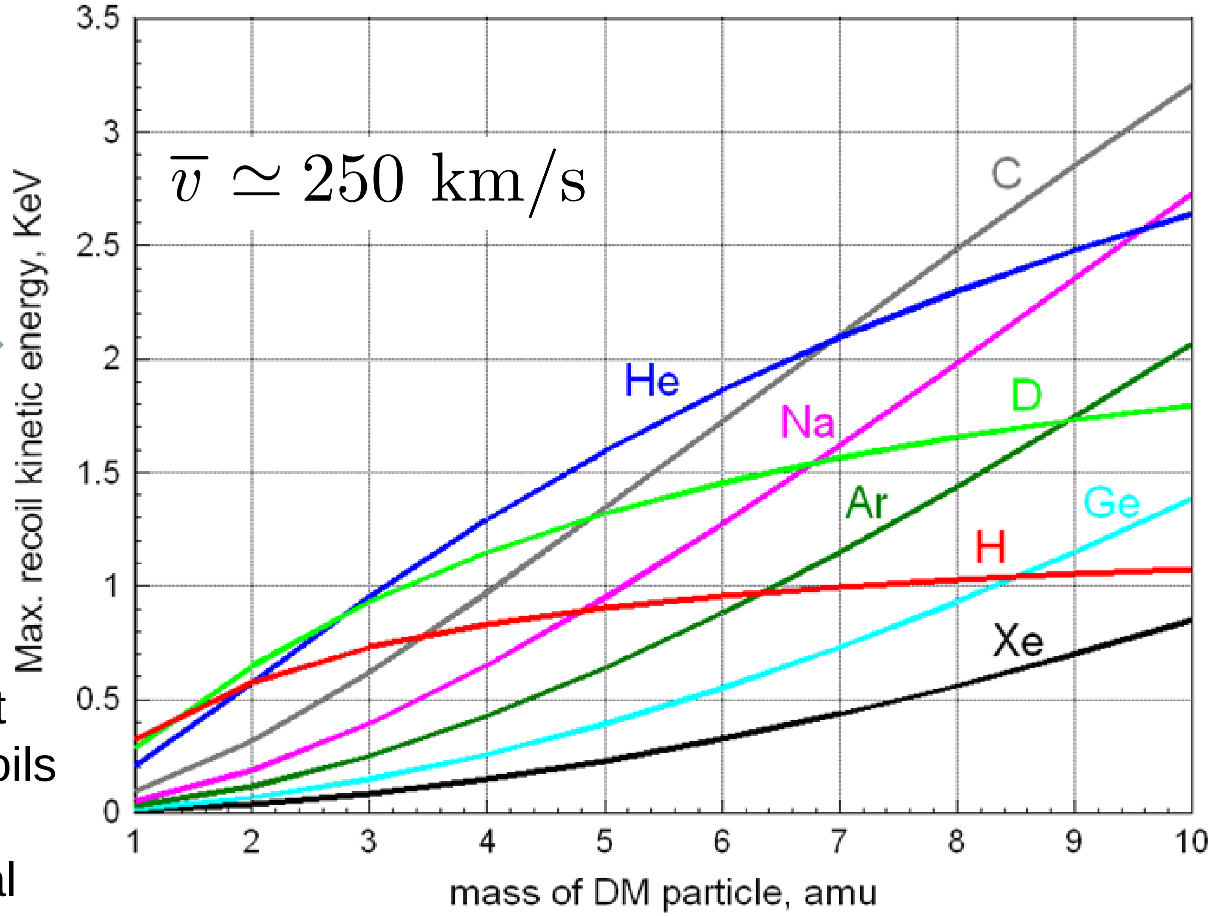
J. Feng and S. Ritz, "Snowmass Cosmic Frontier," (2 Nov. 2013), 7
<http://hep.ps.uci.edu/~jlf/research/presentations/1311P5.pdf>

Why low masses are difficult to detect?

$$T_{recoil}(\max) = T_0 \frac{4m_{nuc}M_{DM}}{(m_{nuc}+M_{DM})^2}$$

CDMS-Si
7 keV

DAMA-Na
2 keV



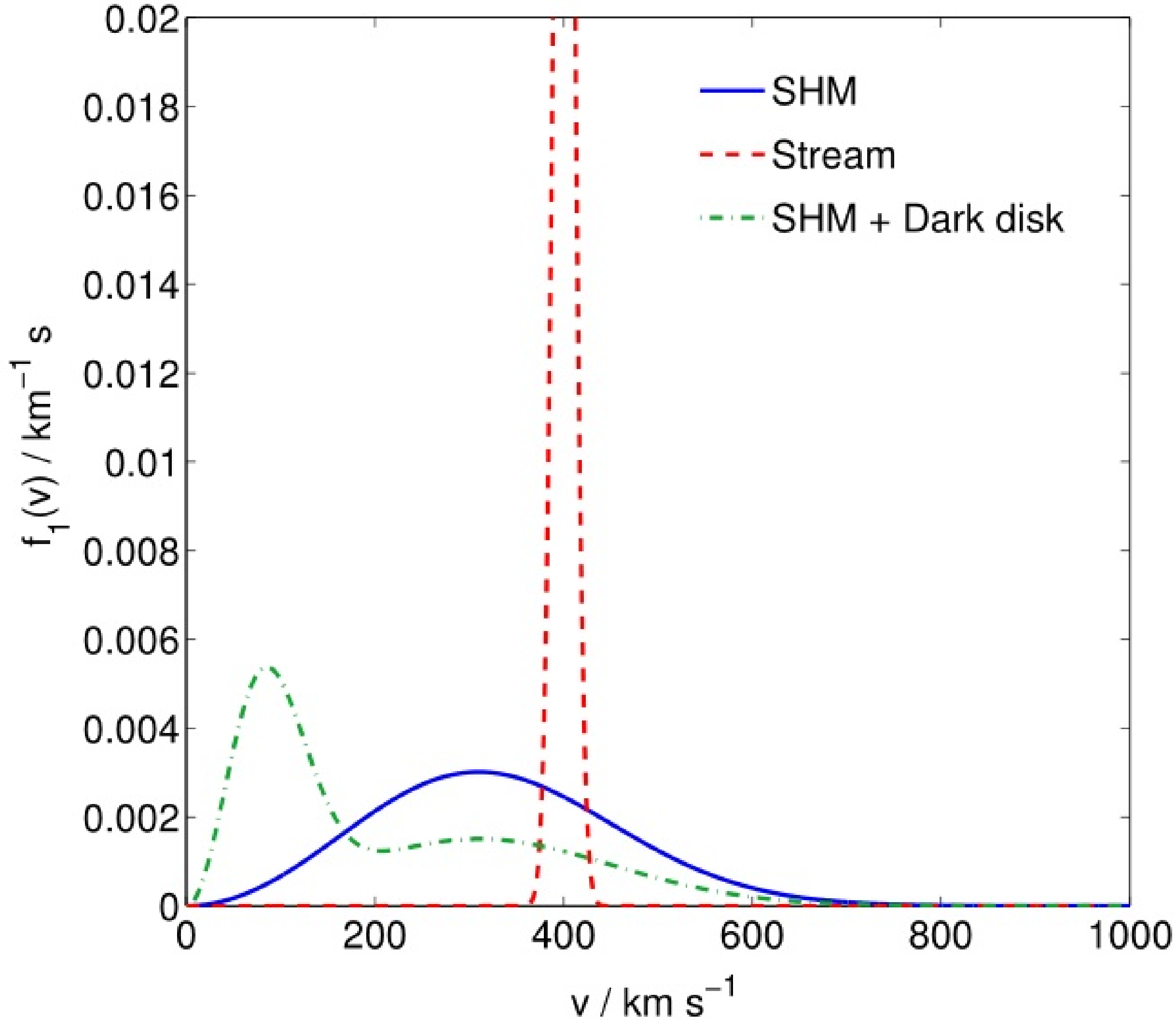
For MM direct detection recoils ≪ 1 keV are most essential

Why low masses are difficult to detect?

- Energy transfer to the nucleus might not result into ionization or excitations of the target atom. After collision with DM the whole atom can be moving as a neutral object. However, in some cases neutral atom can ionize and excite other atoms. In most cases energy going into heat (quenching) is difficult to calculate or determine experimentally.

- Calibration is difficult. E.g. slow neutrons scattering signal << 1 keV that can be used for recoil calibration might not be entirely equivalent to DM recoil due to Schwinger scattering of neutron magnetic moment on the bound electrons of the inner shells.

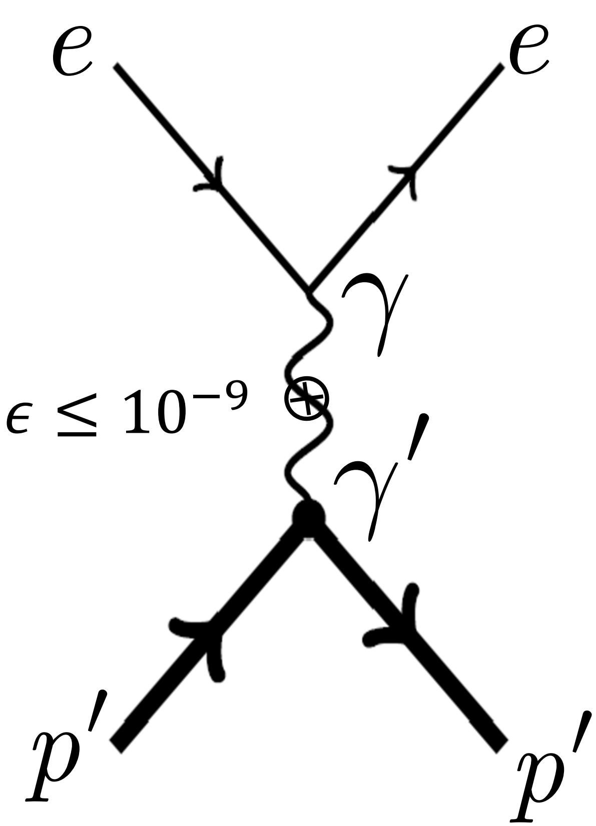
Usual Velocity Distribution Models of DM



B. J. Kavanagh et al., arXiv:1308.6868v2

Interactions of MM with OM nuclei.

Kinetic photon mixing
“Holdom particle”
B. Holdom, Phys. Lett 166B, 196 (1986)



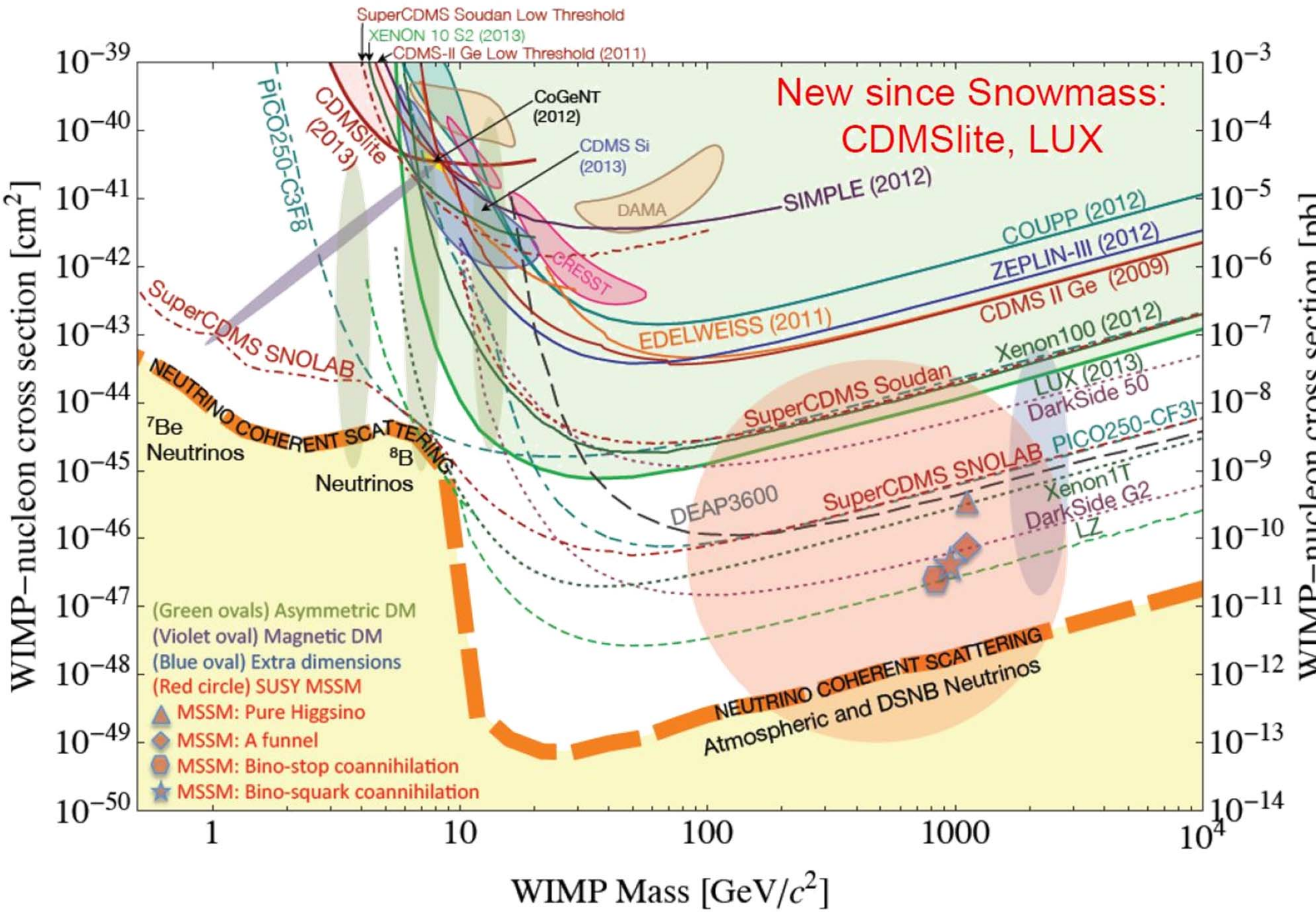
$$\frac{d\sigma}{dT} \sim \frac{1}{T^2}$$

Or short-range interaction
similar to N-N

$$\frac{d\sigma}{dT} \sim const$$

The strength of these interactions is a priori unknown

Dark Matter Direct Detection: Current and Future



J. Feng and S. Ritz, "Snowmass Cosmic Frontier," (2 Nov. 2013), <http://hep.ps.uci.edu/~jlf/research/presentations/1311P5.pdf>

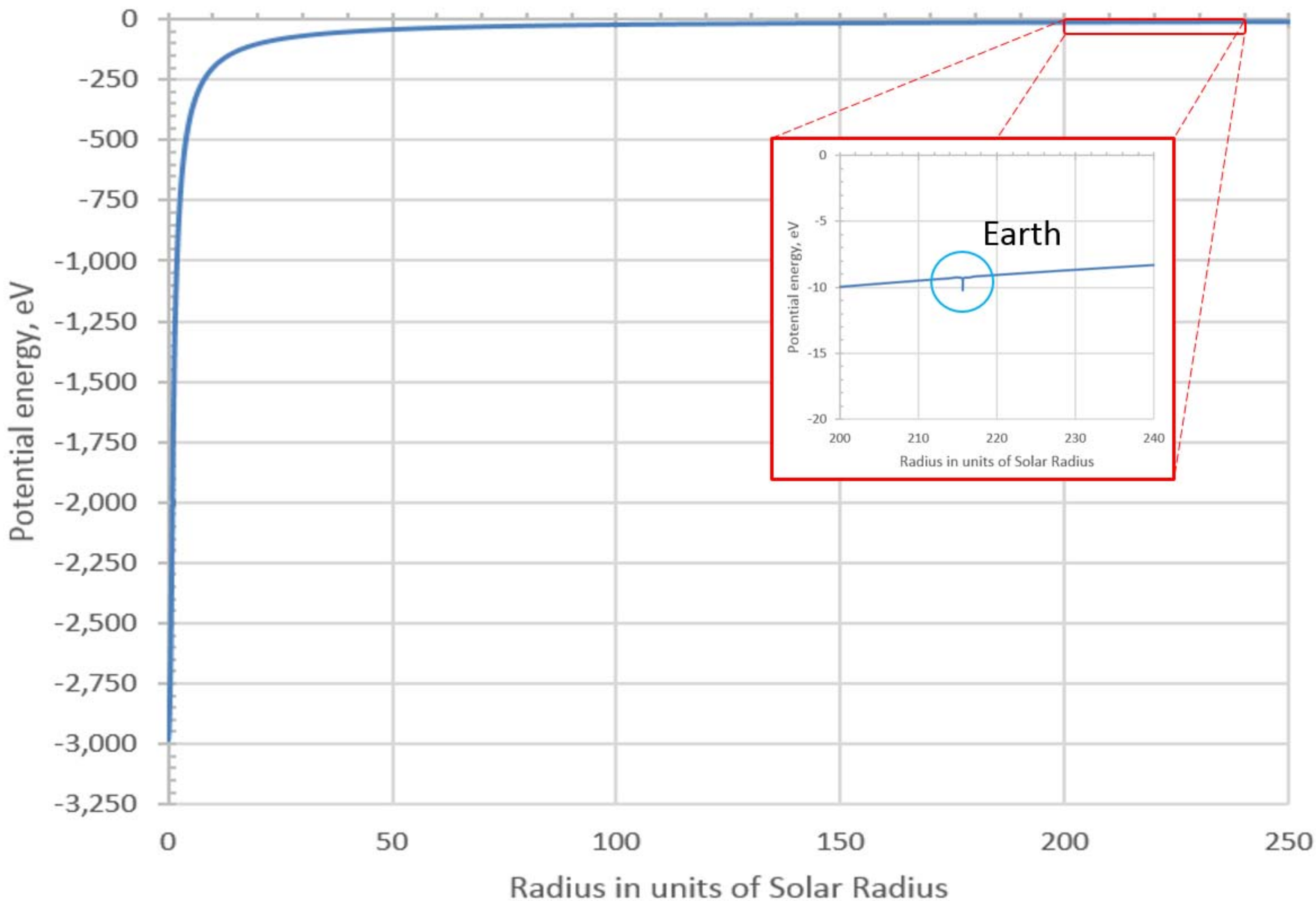
OM Cloud Types ~ MM Cloud Types

Table 1: Components of the interstellar medium[2]

Component	Fractional Volume	Scale Height (pc)	Temperature (K)	Density (atoms/cm³)	State of hydrogen	Primary observational techniques
Molecular clouds	< 1%	80	10—20	10^2—10^6	molecular	Radio and infrared molecular emission and absorption lines
Cold Neutral Medium (CNM)	1—5%	100—300	50—100	20—50	neutral atomic	H I 21 cm line absorption
Warm Neutral Medium (WNM)	10—20%	300—400	6000—10000	0.2—0.5	neutral atomic	H I 21 cm line emission
Warm Ionized Medium (WIM)	20—50%	1000	8000	0.2—0.5	ionized	Hα emission and pulsar dispersion
H II regions	< 1%	70	8000	10^2—10^4	ionized	Hα emission and pulsar dispersion
Coronal gas Hot Ionized Medium (HIM)	30—70%	1000—3000	10^6—10^7	10^{-4}—10^{-2}	ionized (metals also highly ionized)	X-ray emission; absorption lines of highly ionized metals, primarily in the ultraviolet

Wikipedia, "Interstellar Medium"
K. Ferriere

To accumulation of H in Solar system



Developing new MM Detection Model

- Galactic MM by its origin in the gravitational formation (not predicted in details) might be moving inside the galaxy relative to Solar system. Can it be partially co-moving with the local Solar system domain?
- Annual modulations observed by DAMA/LIBRA tell us that relative motion of MM in respect to the Solar motion in galaxy should exists, but relative magnitude should be considered as a parameter.
- Masses of MM particles are fixed. In the direct detection of MM we should consider Hydrogen (~25% by mass), Helium (~ 75%) and "metals" (~ few % by mass). Density of DM in the local vicinity of Solar system can be possibly enhanced by MM accumulation in Solar system.
- In collision of A′ (MM) with detector's A (OM) cross section (if relative velocities are not very high) should be coherent:

$$\sigma_{A'A} = \sigma_{N'N} \cdot A'^2 \cdot A^2$$

- If distribution of A′ masses is given by the MM model, then unknown $\sigma_{N'N}$ and unknown local density of MM can be combine into one unknown parameter

$$(\sigma_{N'N} \cdot \rho_{MM})$$

Fixed by MM Model

1. Masses of MM particles: H, He, % metals
2. Abundances of MM particles in clouds are fixed by models and OM similarity
3. Coherent MM-OM interaction cross section ~ A^2 and A'^2
4. Inside MM clouds components are thermalized.

Parameters

1. Galactic MM clouds have temperature **T** (in its CM system)
2. MM cloud is moving parallel to the direction of Sun motion in galaxy $\boldsymbol{v}_{\parallel}$ (responsible for annual modulation of DAMA/LIBRA observations)
3. Component of relative velocity $\perp$ to direction of solar motion in galaxy (increase above threshold detectability of DM) $\boldsymbol{v}_{\perp}$
4. Nucleon - mirror nucleon cross section $\sigma_{nn'} \times local \; \mathrm{DM} \; density$
5. Type of MM-OM interaction: photon kinetic mixing; contact (like n-A); pion-0 kinetic mixing?

Research Ideas

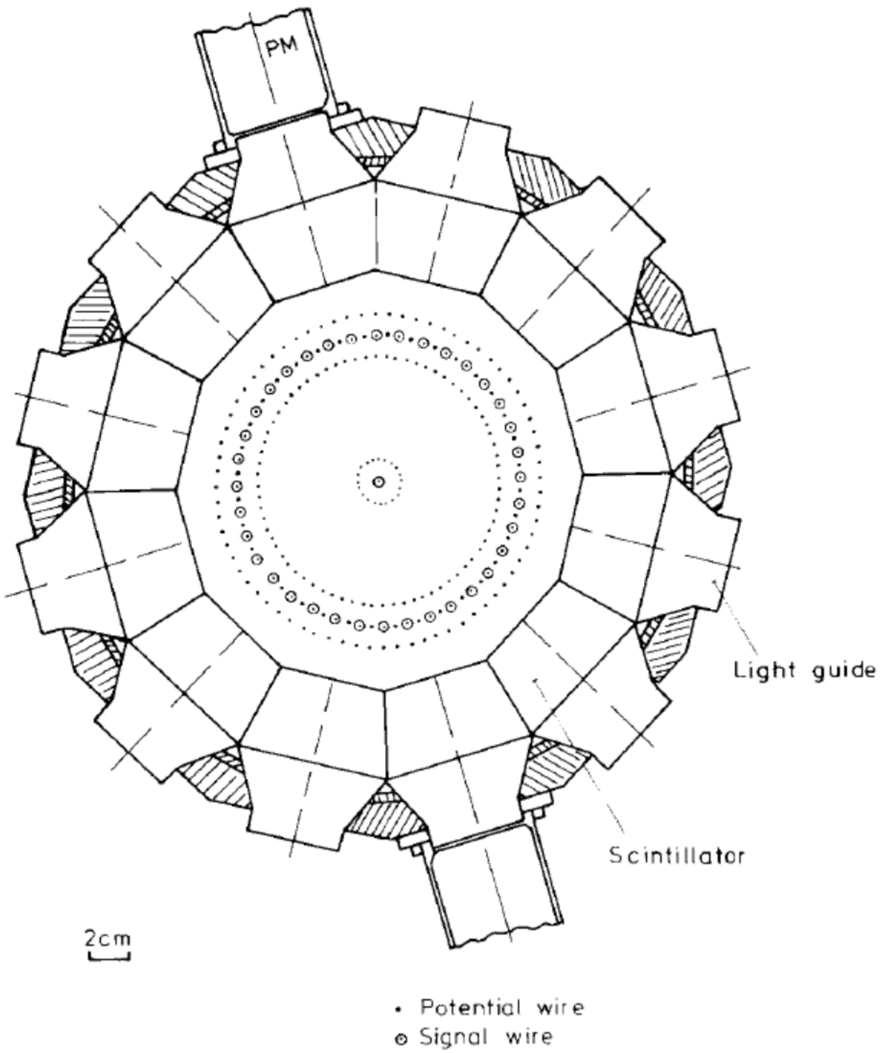
- Using MM Model (and in term of Parameters) determine for all existing direct DM search experiments consistent common region of parameters in multi-dimensional parameter space. Consistent description of all existing experiments might be possible.

- Similar effort of R. Foot "Direct detection experiments explained with mirror dark matter", Physics Letters B 728 (2014) 45-50, is not following exactly the same MM paradigm for detection.

- Develop proposals for direct detection of mirror H, D, He within parameter space determined above. Detectors that can be explored are e.g. gaseous (high pressure) proportional detectors with H_2, D_2, CH_4 following experience of some authors in CERN experiment NA-6:
  A. Arefiev et al, Nuclear Physics B232 (1984) 365-397

- Quenching calculations for hydrogen H_2 can be explicitly performed with atomic theory (e.g. S. Ovchinnikov, at UTK)

(b)



Nuclear Physics B232 (1984) 365–397
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MEASUREMENT OF np ELASTIC SCATTERING AT HIGH ENERGIES AND VERY SMALL MOMENTUM TRANSFERS

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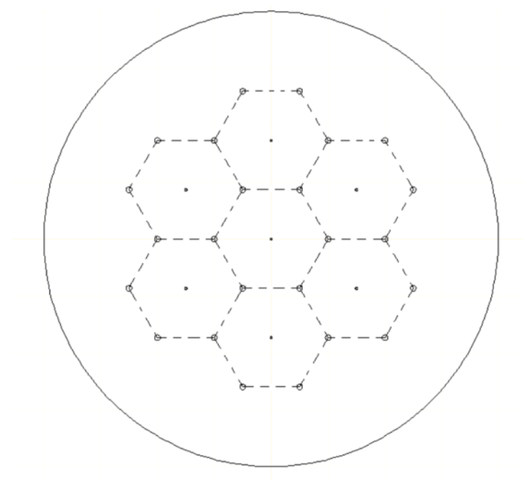

Possible DM detector configuration

Light Dark Matter Detector

A. H_2 gas at 20°C and 1 atm gas ρ=0.0838 g/l (compare with liquid is 0.0708 g/cm^3)

Assume detector fiducial volume of length 1 m and diameter 0.8 m
Volume V= $10 \cdot \pi \cdot 4^2$ liters $\approx$ 500 l
Assume working pressure 50 atm, then density ρ=4.2 g/l
Then, our fiducial mass is 2 kg.

B. Compare with Dama/Libra; they have 250 kg of NaI where Na is 15.3%.
So, the light nuclei (Na) mass in Dama/Libra is 38.3 kg

C. Number of electronics channels is:
With cell radius 2 cm $\rightarrow$ 400 channels
With cell radius 1.5 cm $\rightarrow$ 710 channels
With cell radius 1.0 cm $\rightarrow$ 1600 channels