Title: Probing Light Dark Matter

Date: Jul 21, 2017 02:00 PM

URL: http://pirsa.org/17070021

Abstract:

Probing New Territory in Dark Matter Direct Detection

- Detecting Bound Dark Matter to the Earth
- Detecting Dark Matter via inelastic channels
- Shadowing Effect

Detecting Bound Dark Matter

DM that get captured by the Earth, can later on recoil in detectors

Damour, Krauss '98,
CK, Catena '16

capture

$$d\dot{N} = 16\pi^2 G M_\oplus \sum_A \frac{\sigma_A}{\beta_+^A} K_A(r_m, e)$$

$$\times \int_{r_m}^{R_\oplus} dr\, n_A(r) \left(1 - \frac{r_m^2}{r^2}\right)^{-1/2} de\, \mathrm{d}r_m \equiv g(r_m, e) de\, dr_m$$

accumulation time

$$T(r_m, e) \equiv \min[N \times \tau(r_m, e), \tau_\oplus] \qquad N = \left(\sum_A \int_0^{\phi_1} n_A(r) \sigma_A \xi(r_m, e) d\phi\right)^{-1}$$

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rate of events: nondirectional

$$\frac{dR}{dE_R} = \kappa \int_0^1 \int_{\frac{1-e}{1+e} R_\oplus}^{R_\oplus} de dr_m \frac{g(r_m, e)}{v^2} \frac{T(r_m, e)}{\tau(r_m, e)} dr_m de$$

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$$d\dot{N} = 16\pi^2 G M_\oplus \sum_A \frac{\sigma_A}{\beta_+^A} \tilde{\kappa}_A(r_m, e)$$

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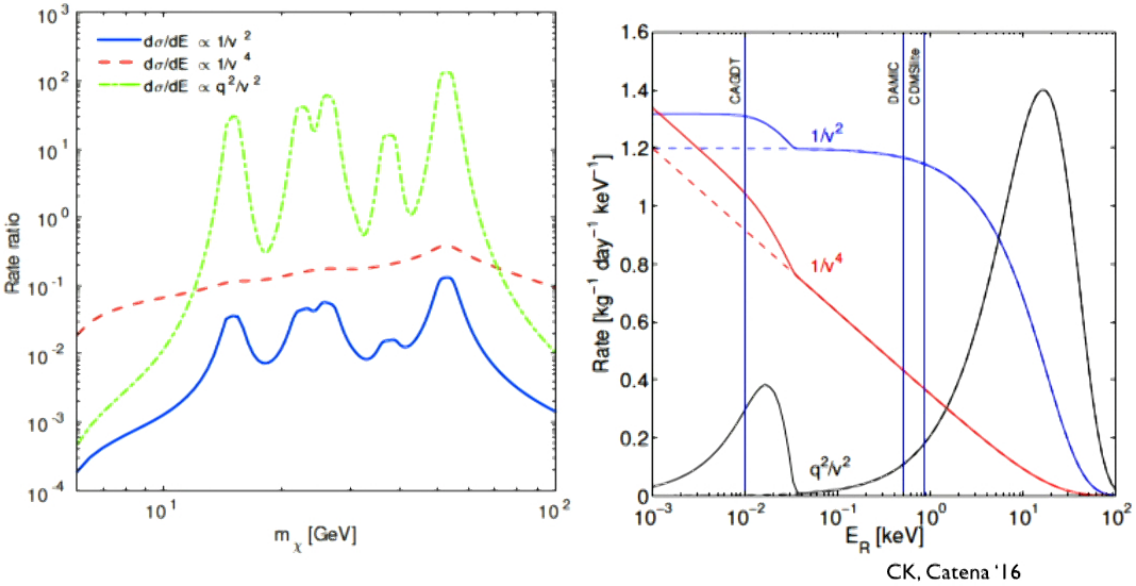
Dark Matter-Nucleus effective interactions

$$\hat{\mathcal{O}}_1 = \mathbb{1}_{\chi N}$$
$$\hat{\mathcal{O}}_3 = i\hat{\mathbf{S}}_N \cdot \left(\frac{\hat{\mathbf{q}}}{m_N} \times \hat{\mathbf{v}}^{\perp}\right)$$
$$\hat{\mathcal{O}}_4 = \hat{\mathbf{S}}_\chi \cdot \hat{\mathbf{S}}_N$$
$$\hat{\mathcal{O}}_5 = i\hat{\mathbf{S}}_\chi \cdot \left(\frac{\hat{\mathbf{q}}}{m_N} \times \hat{\mathbf{v}}^{\perp}\right)$$
$$\hat{\mathcal{O}}_6 = \left(\hat{\mathbf{S}}_\chi \cdot \frac{\hat{\mathbf{q}}}{m_N}\right)\left(\hat{\mathbf{S}}_N \cdot \frac{\hat{\mathbf{q}}}{m_N}\right)$$
$$\hat{\mathcal{O}}_7 = \hat{\mathbf{S}}_N \cdot \hat{\mathbf{v}}^{\perp}$$
$$\hat{\mathcal{O}}_8 = \hat{\mathbf{S}}_\chi \cdot \hat{\mathbf{v}}^{\perp}$$
$$\hat{\mathcal{O}}_9 = i\hat{\mathbf{S}}_\chi \cdot \left(\hat{\mathbf{S}}_N \times \frac{\hat{\mathbf{q}}}{m_N}\right)$$
$$\hat{\mathcal{O}}_{10} = i\hat{\mathbf{S}}_N \cdot \frac{\hat{\mathbf{q}}}{m_N}$$
$$\hat{\mathcal{O}}_{11} = i\hat{\mathbf{S}}_\chi \cdot \frac{\hat{\mathbf{q}}}{m_N}$$
$$\hat{\mathcal{O}}_{12} = \hat{\mathbf{S}}_\chi \cdot \left(\hat{\mathbf{S}}_N \times \hat{\mathbf{v}}^{\perp}\right)$$
$$\hat{\mathcal{O}}_{13} = i\left(\hat{\mathbf{S}}_\chi \cdot \hat{\mathbf{v}}^{\perp}\right)\left(\hat{\mathbf{S}}_N \cdot \frac{\hat{\mathbf{q}}}{m_N}\right)$$
$$\hat{\mathcal{O}}_{14} = i\left(\hat{\mathbf{S}}_\chi \cdot \frac{\hat{\mathbf{q}}}{m_N}\right)\left(\hat{\mathbf{S}}_N \cdot \hat{\mathbf{v}}^{\perp}\right)$$
$$\hat{\mathcal{O}}_{15} = -\left(\hat{\mathbf{S}}_\chi \cdot \frac{\hat{\mathbf{q}}}{m_N}\right)\left[\left(\hat{\mathbf{S}}_N \times \hat{\mathbf{v}}^{\perp}\right) \cdot \frac{\hat{\mathbf{q}}}{m_N}\right]$$

A "smoking gun" for direct detection



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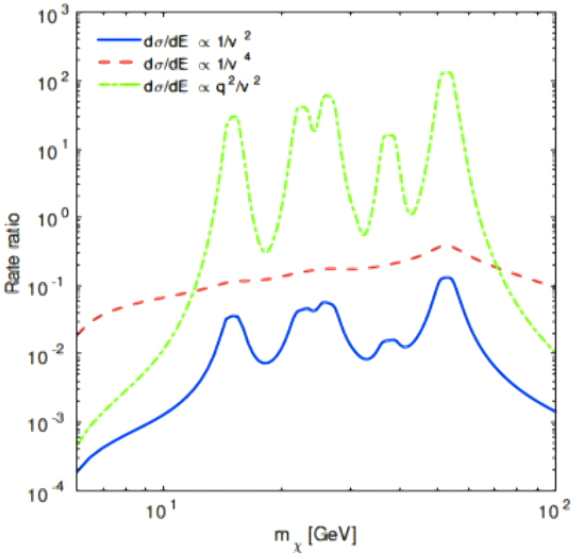

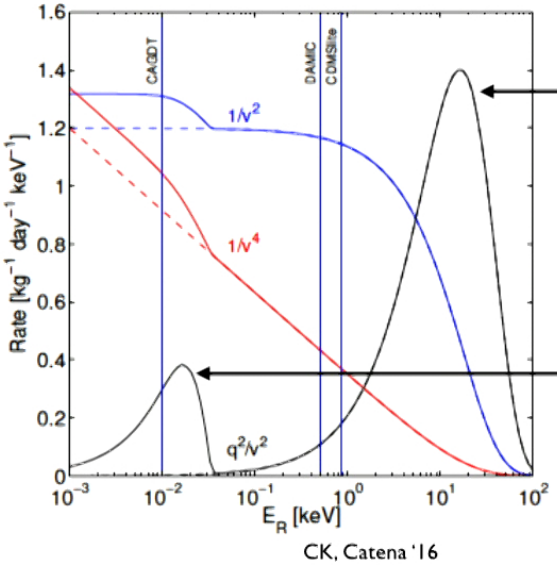

halo DM

bound DM ~400 larger rates than halo DM!

CK, Catena '16

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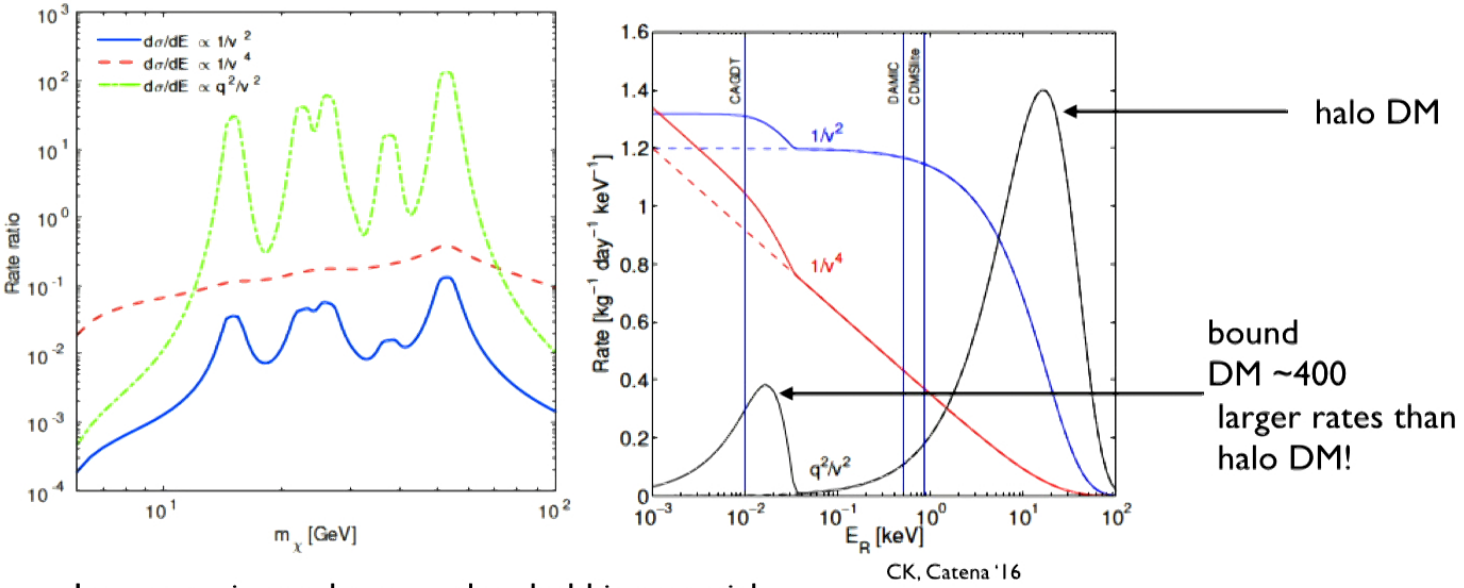


CK, Catena '16

Low experimental energy threshold is essential

Go beyond the neutrino floor

Ratio bound/halo independent of cross section

The signal can be used for identifying the type of interaction

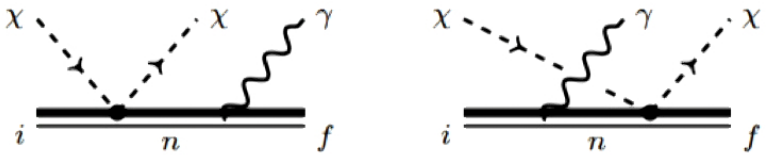
Probing sub-GeV Dark Matter

A given nuclear recoil requires a minimum velocity $v_{\rm min} = \sqrt{\frac{m_N E_R}{2\mu_N^2}}$

$$E_R \leq 2\mu_N^2 v^2 / m_N$$

see Pradler's talk!

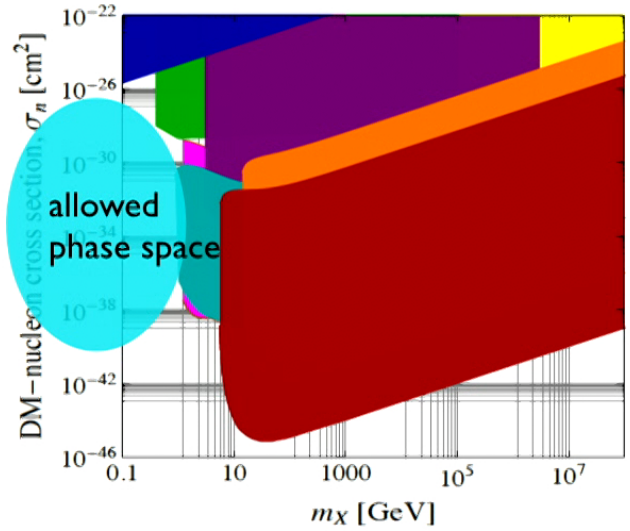
Inelastic Scattering



$$\omega \leq \mu_N v^2 / 2$$

The photon energy can be much larger than the nuclear recoil

Looking for Dark Matter in the Earth's Shadow



CK, Shoemaker '14

There is light dark matter phase space that will not be covered by underground experiments even if they lower their energy threshold due to effective stopping by the rock.

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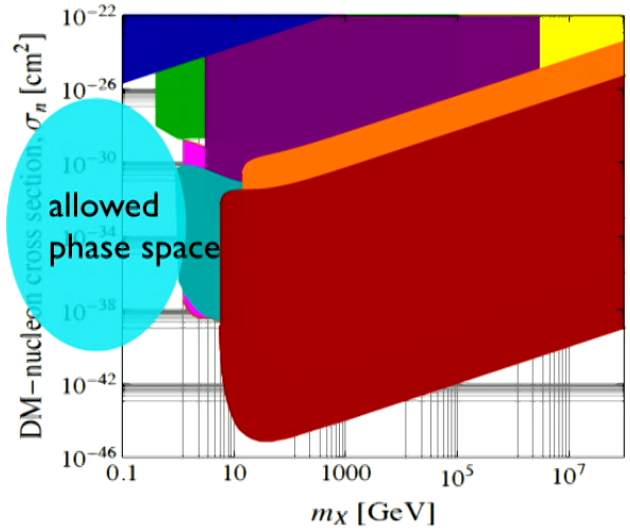

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Need for detectors in shallow sites or on surface
However this would increase the background!

Observing a daily varying dark matter signal
Avignone Collar '92, CK, Shoemaker '14, Foot Vagnozzi '15

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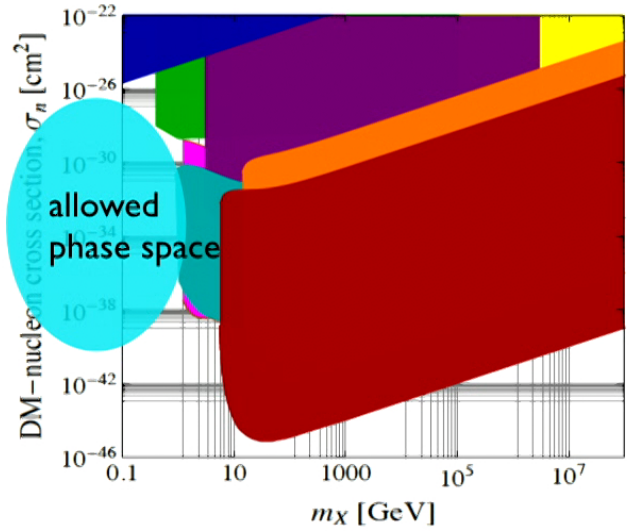

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- Ideal for portable detectors like DAMIC can be placed either on the surface or in shallow sites
- Best latitude at the south hemisphere ~43 degrees. Chile, Argentina, Australia, New Zealand

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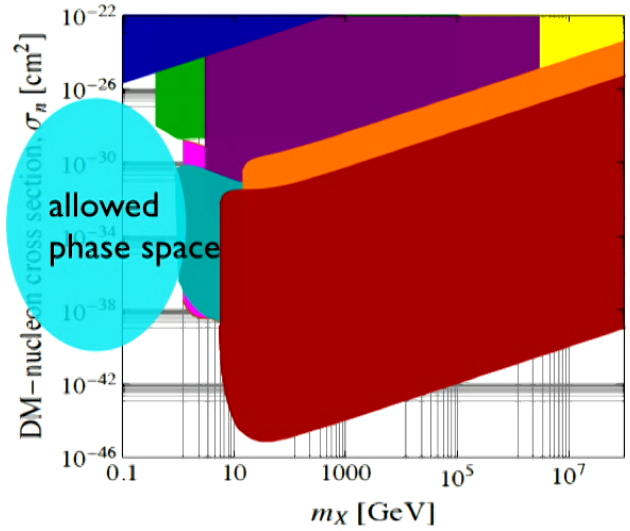

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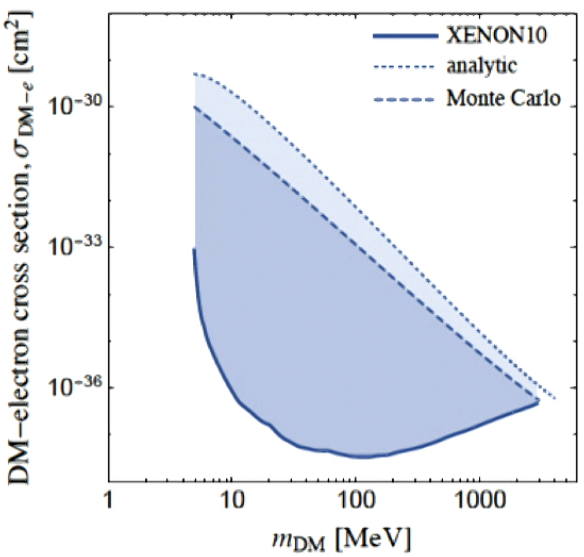
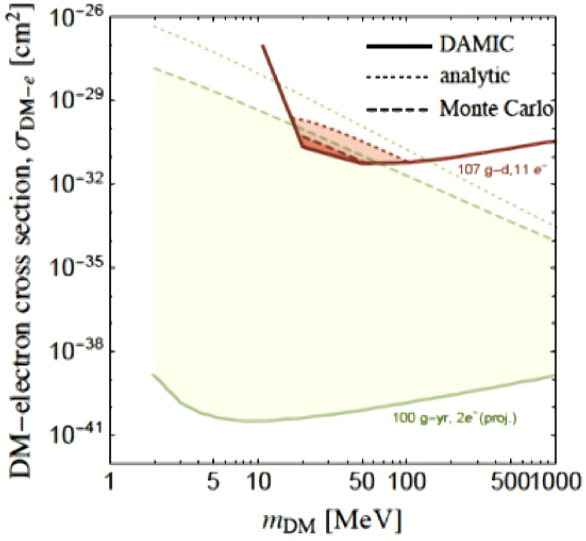
The effect can be probed also in directional detectors manifesting itself as a top-down asymmetry CK'15

Re-visiting Direct Detection Limits

$$\mathscr{L} \supset g_X \bar{X} \gamma^\mu X A'_\mu + \varepsilon F_{\mu\nu} F'^{\mu\nu} + m_\phi^2 A'_\mu A'^\mu$$





Emken, CK, Shoemaker '17

Experiment	Depth [m]	$E_{th,r}$[eV]
XENON10	1400	12.4
DAMIC	100	40
DAMIC (proj.)	100	$\sim 1-2$

Daily Modulation in the Dark Matter Signal

The dark matter signal in underground detectors has three types of diurnal modulation:

- Shadowing effect
- Gravitational focusing
- Rotational velocity of the Earth

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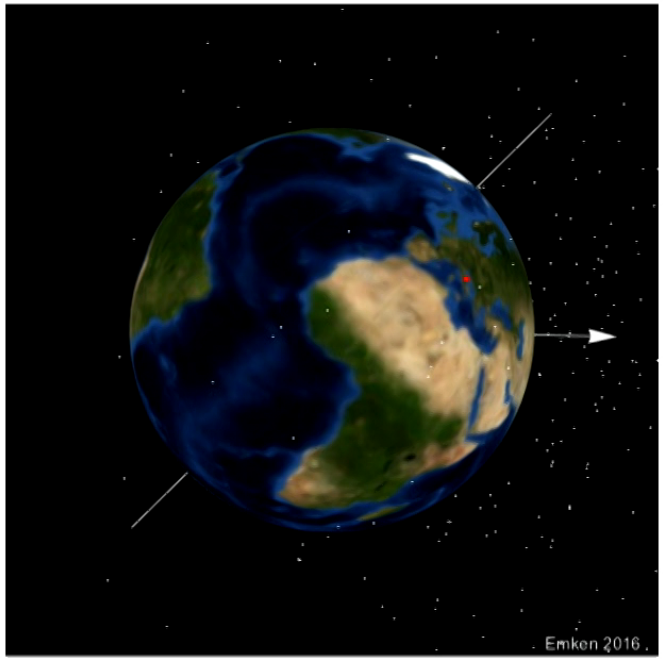
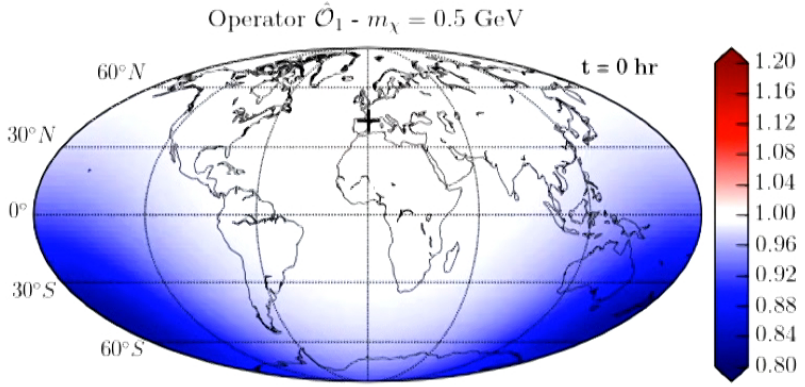


The Shadow of the Earth



Relative rate enhancement due to Earth-scattering *(attenuation only)*

(Kavanagh, CK, Catena '17)

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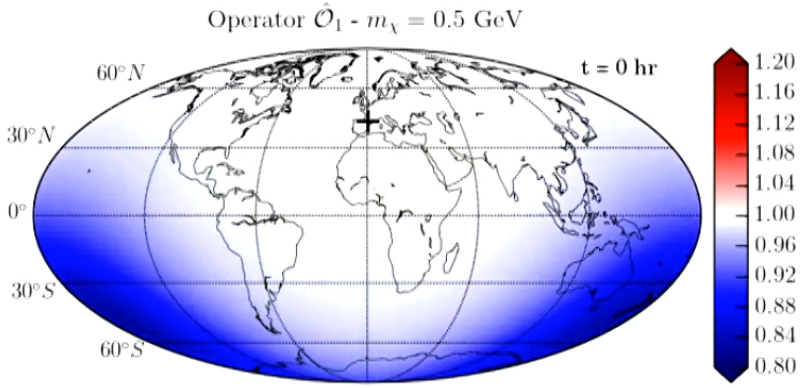

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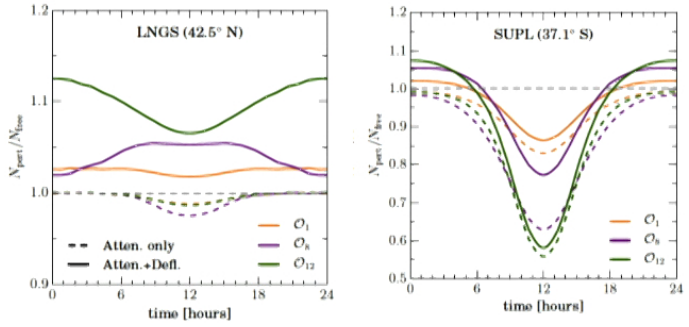
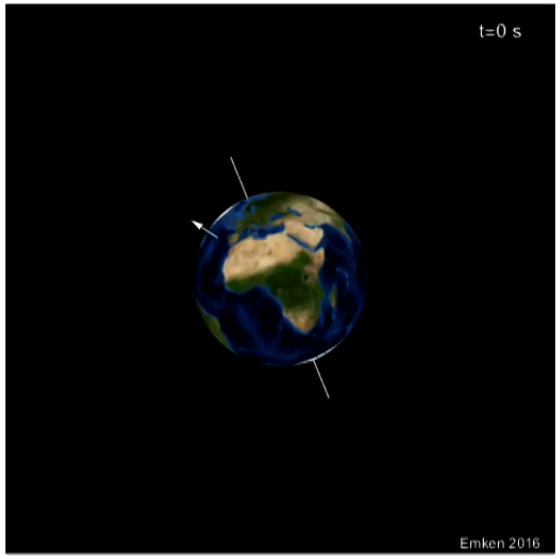
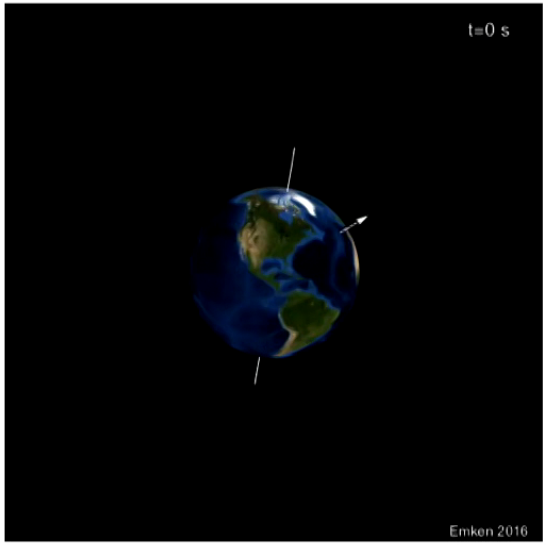


DAMASCUS: Dark Matter on Supercomputers

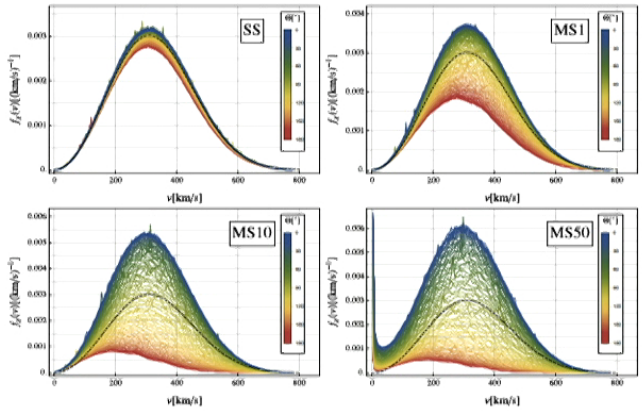
Performing a simulation of trillions of DM particles on ABACUS

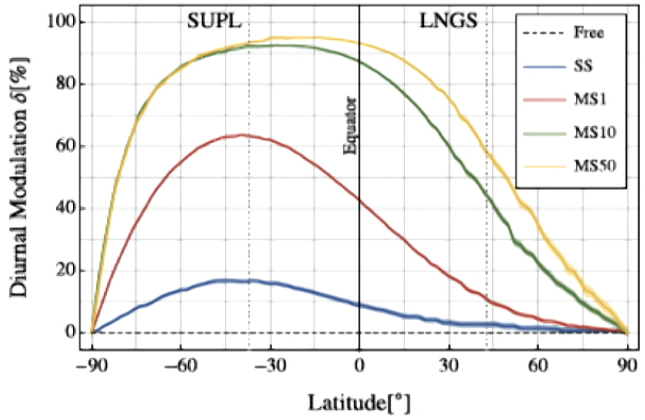
- fully parallelized code
- Precise Recoil Spectrum
- Test self-consistency of experiments
- Probe Currently Elusive Dark Matter





DAMASCUS running on high cross section





Conclusions

Bound Dark Matter

- Universal feature at low recoil energies
- Identification of the type of DM-nucleon interaction
- Neutrino Floor

Probing Light Dark Matter in Direct detection via Inelastic processes

- Probing sub-GeV DM

Probing Light Dark Matter using the daily modulation DM signals from

- Phase space not covered by current detectors
- self-consistency of diect detection experiments