Status of direct detection experiments
~~Certainties~~ and uncertainties

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Roadmap

PART I

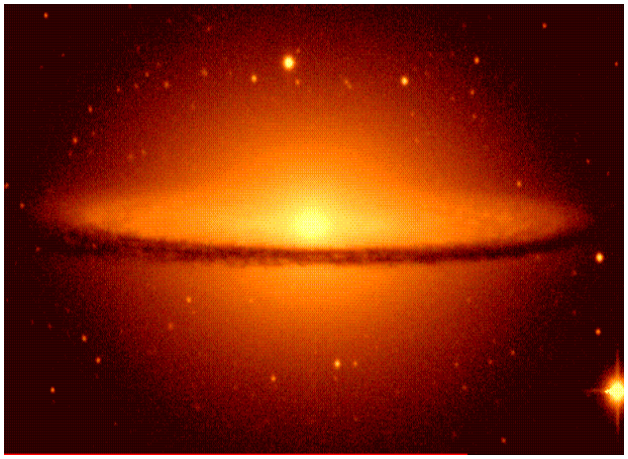
- Direct detection hints for a dark matter signal
- Uncertainties

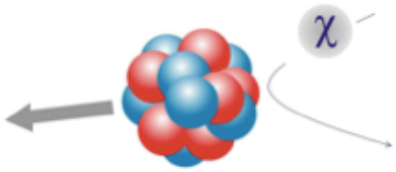
PART II by JURE

- Effects of various uncertainties on dark matter parameter regions
- Outlook

Direct detection of WIMPs

- Don't know matter-dark matter interactions! Could naturally be very small, e.g. gravitino, axion, FIMP etc.
- Assume non-negligible interactions, motivated by "WIMP-miracle"





PHYSICAL REVIEW D VOLUME 31, NUMBER 12 15 JUNE 1985

Detectability of certain dark-matter candidates

Mark W. Goodman and Edward Witten
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544
(Received 7 January 1985)

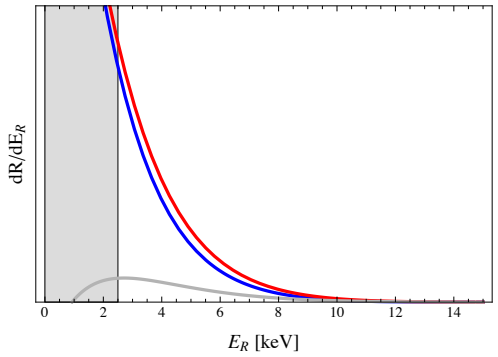
- Idea: look for the nuclear recoil due to dark matter scattering
- What key signatures to expect?

DM Scattering

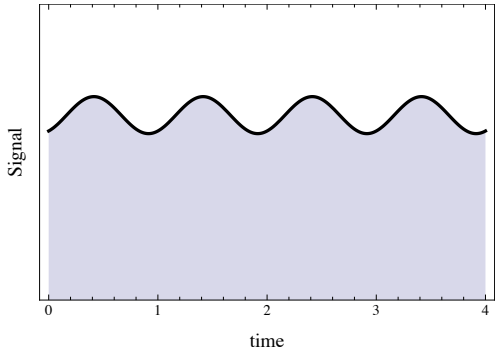
- Scattering of ~100 GeV vanilla DM particle with m_A ~100 GeV nucleus with v~10^{-3}:

$$E_R = \frac{2\mu^2 v^2}{m_A}\cos^2\theta_{\rm lab} \sim 10\,{\rm keV} \qquad v_{\rm min} = \sqrt{\frac{m_A E_R}{2\mu^2}}, \qquad \mu = \frac{m_\chi m_A}{m_\chi + m_A}$$

- Scattering rate: counts/day/kg detector mass/keV recoil energy



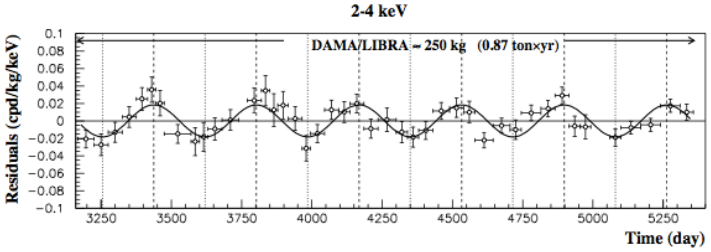
Total rate: subject to background



Annual modulation

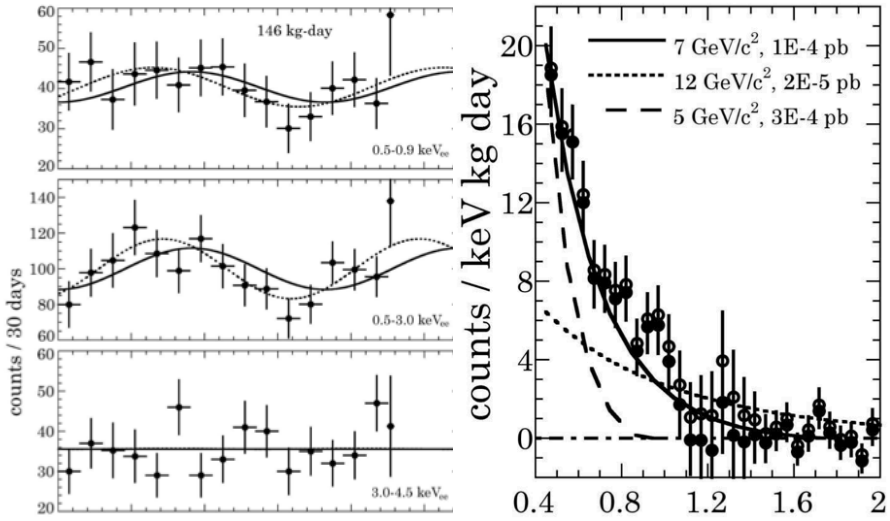
- Many different experiments with different target materials and techniques...

Experimental anomalies



DAMA

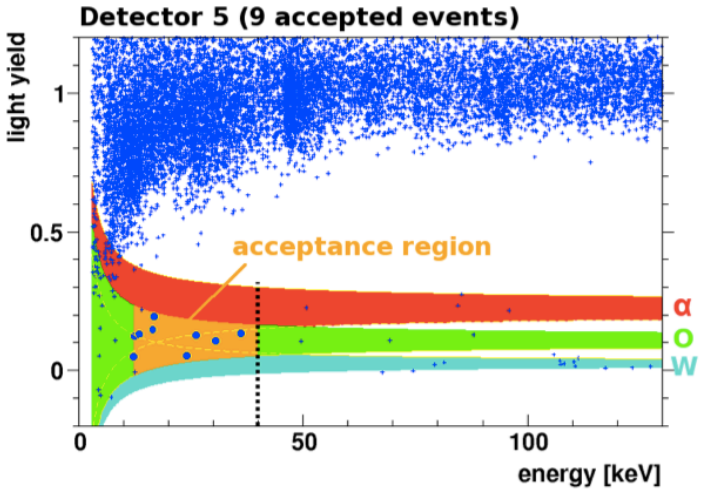
Bernabei et al, 0804.2741, 1002.1028



Aalseth et al, 1106.0650

CoGeNT

Cf. talk by Collar

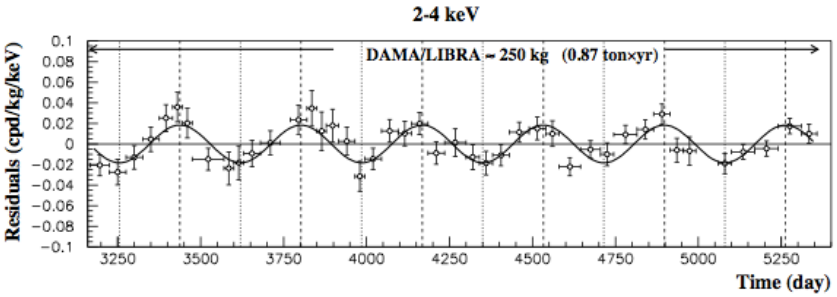


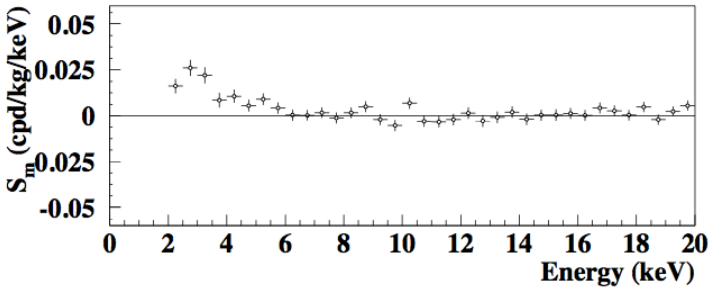
CRESST

Cf. e.g. talk by Seidel @ IDM 2010

DAMA/LIBRA annual modulation signal

Bernabei et al, 0804.2741, 1002.1028





- Scintillation light in NaI detector
- 1.17 t yr exposure (13 years)
- ~ 4 10^5 single hit events per keV
- 8.9σ evidence for annual modulation in energy range of 2-6 keVee

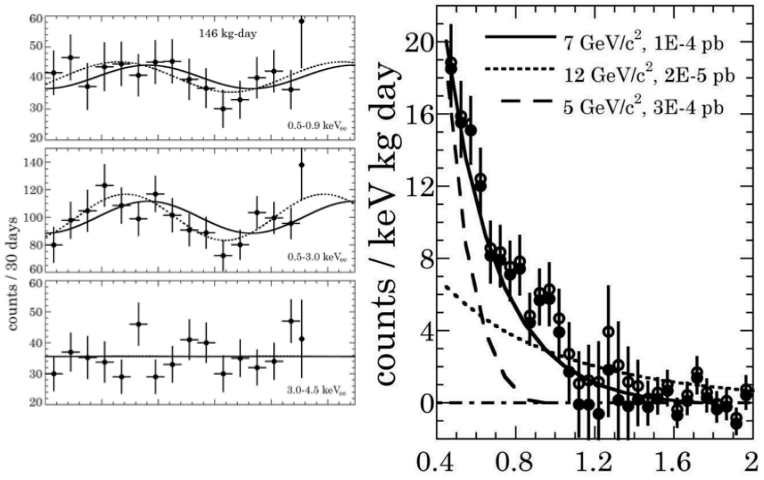
What is it???

- Period and phase (146 ±7, June 2=152) consistent with DM interpretation, energy range looks ok...
- Modulating background? No known 'non-dark matter' explanation

CoGeNT

Cf. talk by Collar

Aalseth et al, 1106.0650



- Low threshold Ge detector with very good resolution
- 442 live days, Exposure ~ 145 kg d

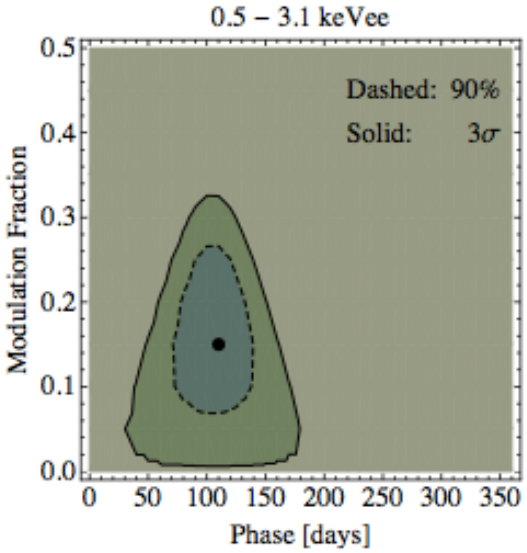
- Exponential event excess at low energies
- ~ 2.8 σ evidence for annual modulation

Triggered recent interest...

Frandsen et al, 1105.3734; Arina et al, 1105.5121; Del Nobile et al, 1105.5431; Pato, 1106.0743; Hooper, Kelso, 1106.1066; Chen, Zhang, 1106.4044; Belli et al, 1106.4647; Schwetz, Zupan, 1106.6241; Farina et al, 1107.0715; Fox et al, 1107.0717; McCabe, 1107.0741

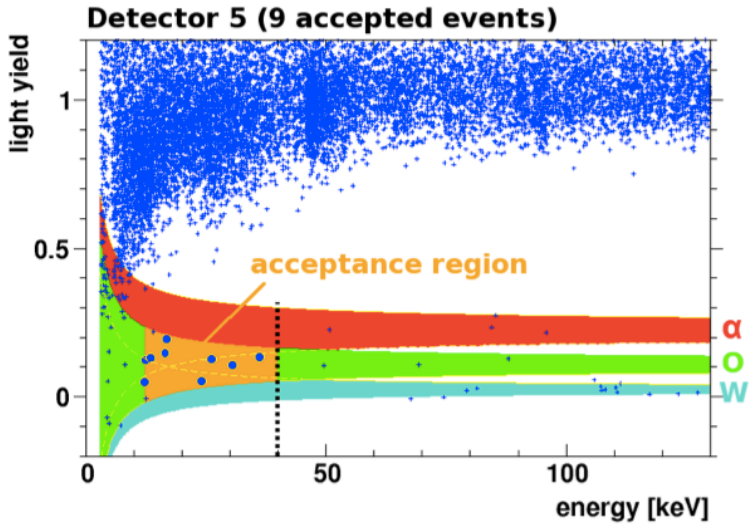
However, some puzzling features:

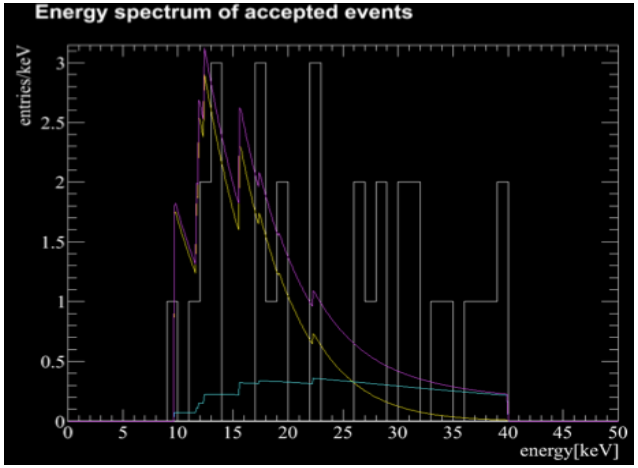
- Peak day rather early, mid April
- Large modulation fraction
- Modulation extends to rather high energies



Fox et al, 1107.0717

CRESST





- 9 $CaWO_4$ detectors
- 57 events in O-band
- Exposure ~ 730 kg d
- Acceptance region ~10-40 keV

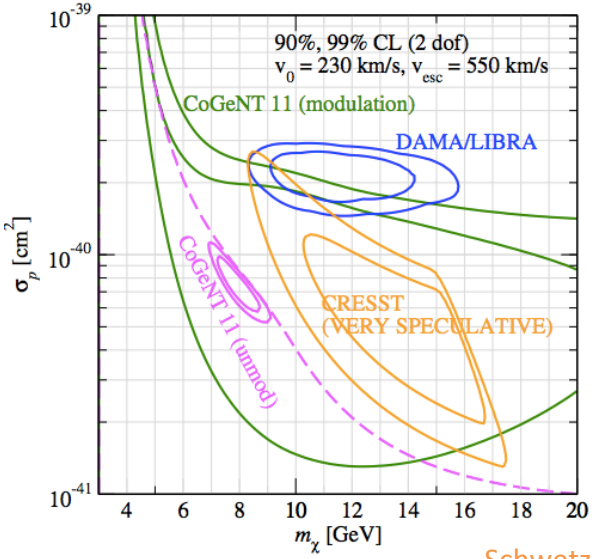
- Estimated background from side bands ~ 35.6

- Excess events cannot be explained by modeled background at 4.6 σ

- Publication soon ?!

Cf. e.g. talk by Seidel @ IDM 2010

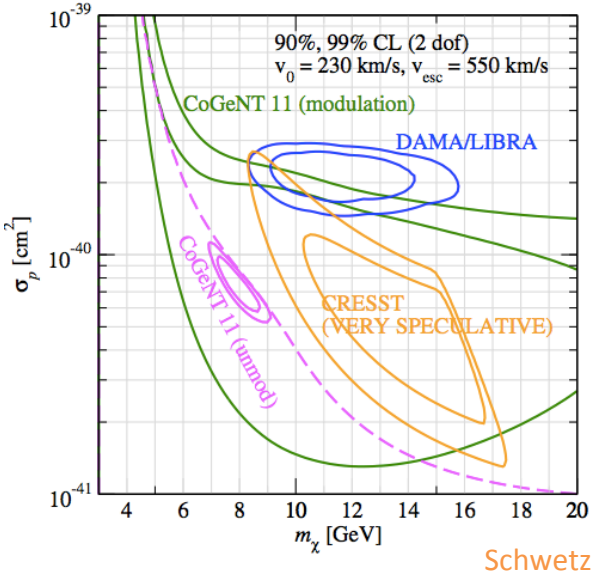
Consistent dark matter interpretation ?



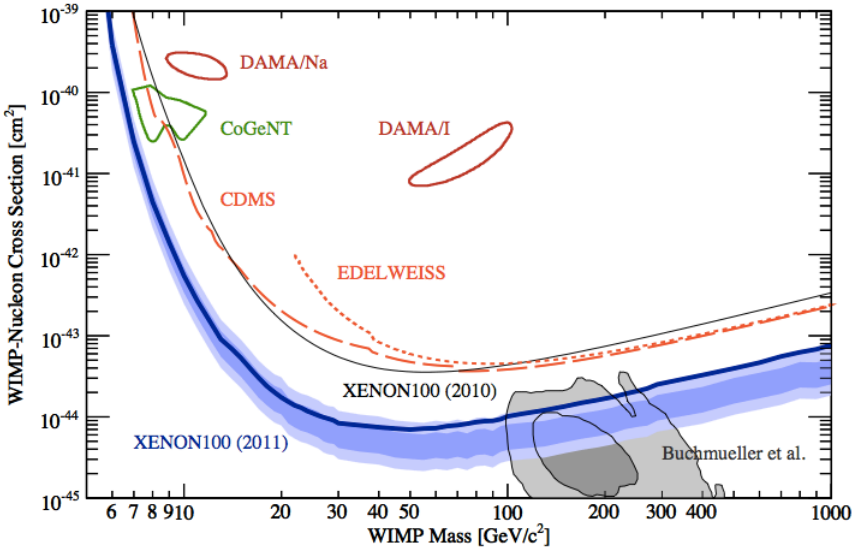
Schwetz

- Preferred parameter regions not completely consistent, but in the same ballpark...

Consistent dark matter interpretation ?



Schwetz



Aprile et al, 1104.2549

- Preferred parameter regions not completely consistent, but in the same ballpark...
- However, the preferred regions seem to be inconsistent with null results from CDMS, XENON
- What are the uncertainties?

What are the uncertainties ?

- Two types of uncertainties:
- (spin-independent) DM-nucleus scattering rate:

$$\frac{\mathrm{d}R}{\mathrm{d}E_R}(E_R,t) = M_{\mathrm{tar}} \frac{\rho_\chi}{2\,m_\chi \mu^2} \frac{(f_p Z + f_n (A-Z))^2}{f_n^2} \sigma_n F^2(E_R) \int_{v_{\mathrm{min}}}^{\infty} \mathrm{d}^3 v \, \frac{f_{\mathrm{local}}(\vec{v},t)}{v}$$

Particle physics — Nuclear physics — astrophysics

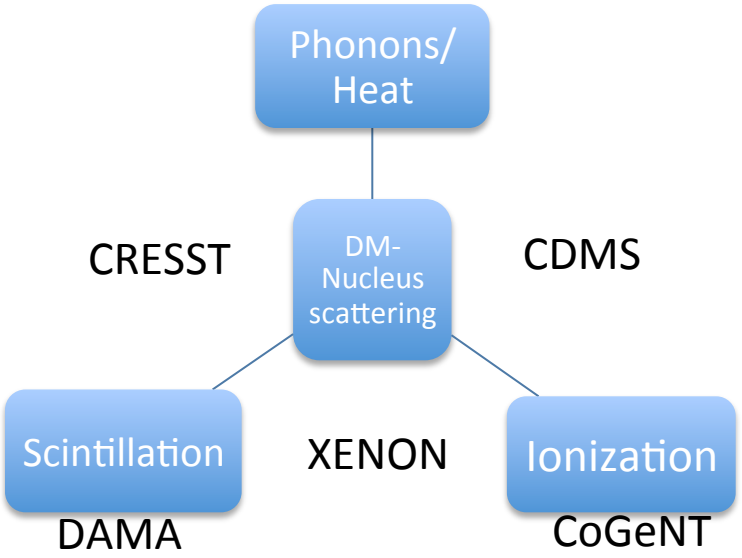
- Additional experimental uncertainties:
- Efficiencies, energy resolution, backgrounds
- In particular light dark matter challenging since close to detector thresholds...

- Translating measured energies into recoil energies

DAMA and CoGeNT are special...

- Is the starting assumption correct?

- DAMA and CoGeNT use only one technique and cannot discriminate between nuclear and electron recoils



Could dark matter lead to a signal which has been rejected?

- Theoretical ideas: Leptophilic DM, Luminous DM

Fox, Poppitz, 0811.0399; Kopp et al, 0907.3159

Feldstein, Graham, Rajendran, 1008.1988

- CRESST important!

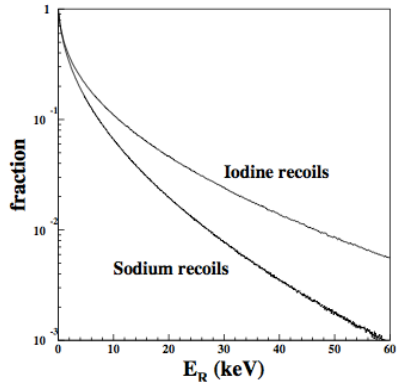
Measured and recoil energies - DAMA

- Quenching factor for Na?
  Different measurements:
  DAMA 'default value' $Q_{Na} = 0.3 \pm 0.01$
  $Q_{Na} = 0.33 \pm 0.15$ Tovey et al, Phys. Lett. B433 (1998)
  $Q_{Na} = 0.252 \pm 0.065$ Chagani, Majewski, Daw, 0806.1916

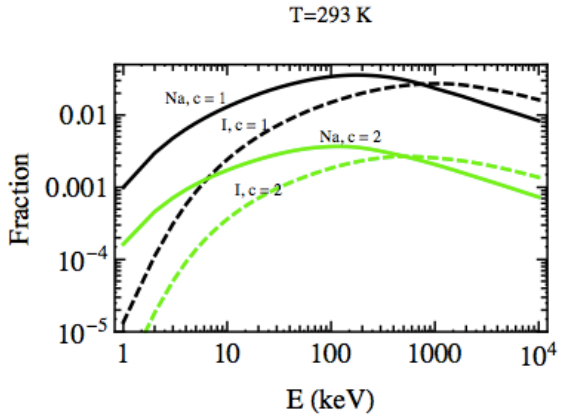
Higher value could alleviate tension...

Hooper, Collar, Hall, McKinsey, 1007.1005

- Channeling in NaI(Tl)? Some fraction of events scatter parallel to a symmetry axis, depositing the entire energy in scintillation, Q≈1



Bernabei, 0710.0288



Bozorgnia, Gelmini, Gondolo, 1006.3110

Measured and recoil energies - XENON

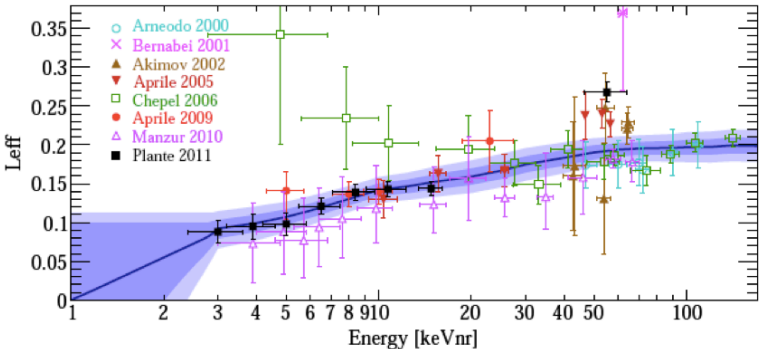
Cf. talk by Bruch

- S1 primary scintillation, S2 delayed ionization signal
- translate number of photo electrons S1 into recoil energy

$$S1 = \frac{S_{nr}}{S_{ee}} L_y \, \mathcal{L}_{\text{eff}}(E_R) \, E_R \simeq 3.6 PE \, \mathcal{L}_{\text{eff}}(E_R) \, E_R$$

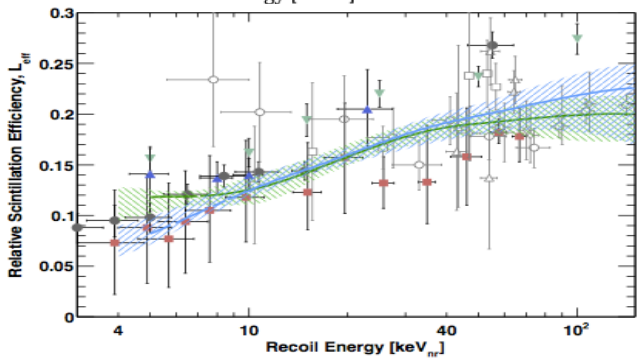
Heated discussion: Collar, McKinsey, 1005.0838;
XENON100, 1005.2615;
Savage et al, 1006.0972, Sorensen, 1007.3549;
Collar, 1006.2031, 1106.0653

Aprile et al, 1104.2549



- Correlation between Scintillation and Ionization suggests non-vanishing L_{eff}

Bezrukov, Lindner, Kahlhoefer, 1011.3990



Horn et al, 1106.0694

Astrophysical uncertainties

Cf. Talk by Green

$$\frac{\mathrm{d}R}{\mathrm{d}E_R}(E_R,t) = M_{\mathrm{tar}} \frac{\rho_\chi}{2 m_\chi \mu^2} \frac{(f_p Z + f_n (A-Z))^2}{f_n^2} \sigma_n \, F^2(E_R) \int_{v_{\mathrm{min}}}^{\infty} \mathrm{d}^3 v \, \frac{f_{\mathrm{local}}(\vec{v},t)}{v}$$

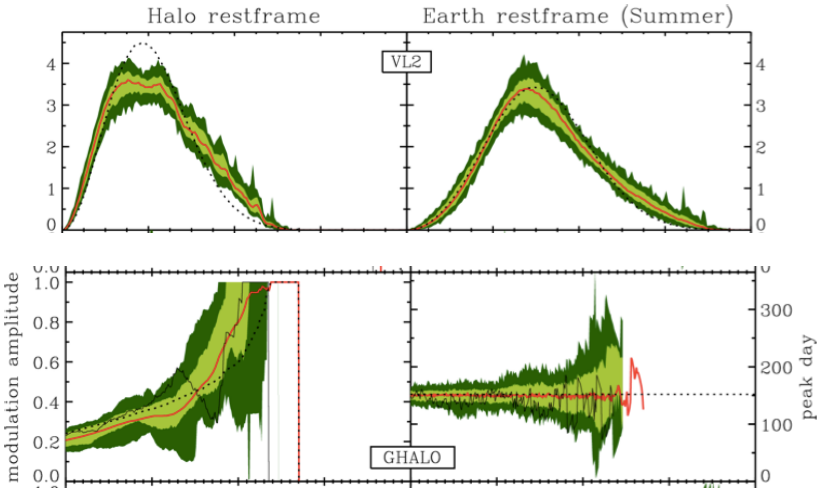
$$\rho_\chi \approx 0.389 \pm 0.025 \,\mathrm{GeV\,cm^{-3}}$$

Catena, Ullio, 0907.0018

- Parameters of the SHM, v_0, v_{esc},

$$f(\vec{v}) = \begin{cases} \frac{1}{N}\left(e^{-v^2/v_0^2} - e^{-v_{esc}^2/v_0^2}\right) & v < v_{esc} \\ 0 & v > v_{esc} \end{cases}$$

- N-body simulations: Significant deviations from SHM Cf. Talk by Kuhlen
- Particularly important for dark matter sensitive to the velocity tail (e.g. light DM)



Kuhlen et al, 0912.2358

Astrophysical uncertainties

Cf. Talk by Green

- Idea: Look at v_{min} space, astrophysical uncertainties drop out

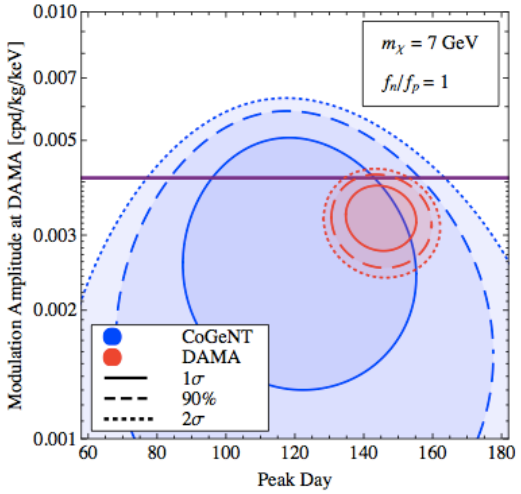
Fox, Liu, Weiner, 1011.1915; Fox et al, 1107.0717

$$\frac{\mathrm{d}R}{\mathrm{d}E_R}(E_R,t) = M_{\mathrm{tar}}\frac{\rho_\chi}{2\,m_\chi\mu^2}\frac{(f_p Z + f_n(A-Z))^2}{f_n^2}\,\sigma_n\,F^2(E_R)\int_{v_{\mathrm{min}}}^{\infty}\mathrm{d}^3v\,\frac{f_{\mathrm{local}}(\vec{v},t)}{v}$$

$= g(v_{min},t)$

$$[E^{(1)}_{\mathrm{low}}, E^{(1)}_{\mathrm{high}}] \Leftrightarrow [v^{\mathrm{low}}_{\mathrm{min}}, v^{\mathrm{high}}_{\mathrm{min}}] \Leftrightarrow [E^{(2)}_{\mathrm{low}}, E^{(2)}_{\mathrm{high}}]$$

$$v_{\mathrm{min}} = \sqrt{\frac{m_A E_R}{2\mu^2}}, \quad \mu = \frac{m_\chi m_A}{m_\chi + m_A}$$



McCabe, 1107.0741

- Given what CoGeNT sees, what should DAMA see and what does DAMA see
- both modulations consistent
- Tension with XENON, CDMS-Ge should see modulation

Fox et al, 1107.0717

Particle physics uncertainties ?

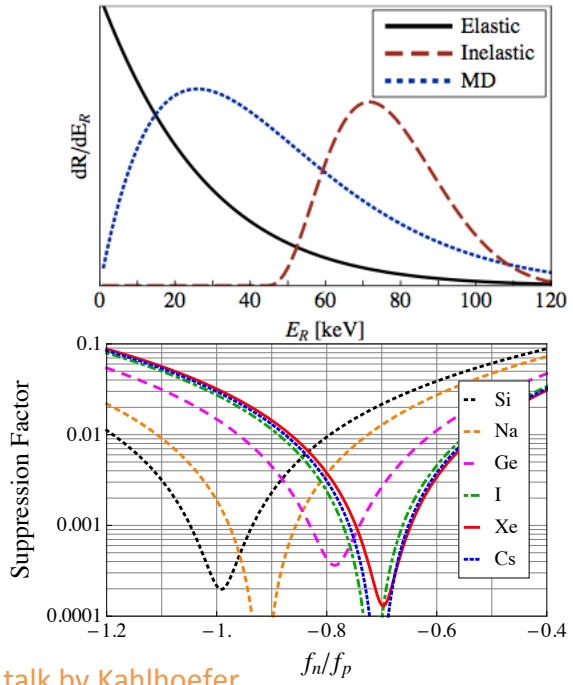
spin-dependent: Jure

- Standard formula for DM-nucleus spin-independent scattering rate:

$$\frac{\mathrm{d}R}{\mathrm{d}E_R}(E_R,t) = M_{\mathrm{tar}}\frac{\rho_\chi}{2\,m_\chi \mu^2}\frac{(f_p Z + f_n(A-Z))^2}{f_n^2}\sigma_n F^2(E_R)\int_{v_{\mathrm{min}}}^{\infty}\mathrm{d}^3 v\,\frac{f_{\mathrm{local}}(\vec{v},t)}{v}$$

What is the underlying particle physics model?

- The dark matter nucleon cross-section could be momentum and/or velocity dependent Feldstein, Fitzpatrick, Katz, 0908:2991, Chang, Pearce, Weiner, 0908.3192
- The scattering could be inelastic Tucker-Smith, Weiner, hep-ph/0101138
- The scattering could be resonant Bai, Fox, 0909.2900
- Dark matter could couple differently to protons and neutrons 'isospin violating dark matter' Kurylov, Kamionkowski, hep-ph/0307185, Giuliani, hep-ph/0504157, …



Cf. talk by Kahlhoefer

Implications of these uncertainties on preferred regions/limits?

Jure!