Mirror dark matter interpretation of DAMA, COGeNT and CRESST-II experiments

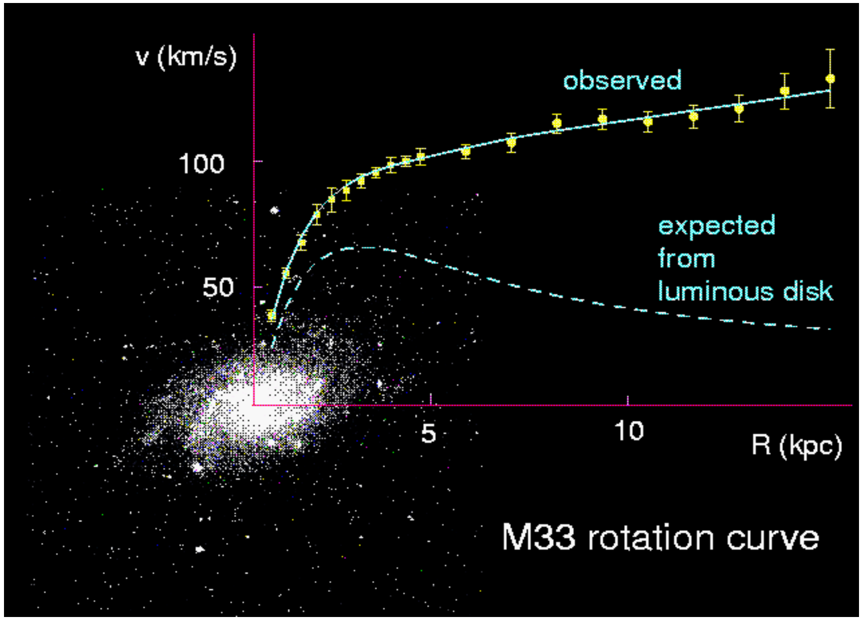
Robert Foot, University of Melbourne

Talk at ICHEP,

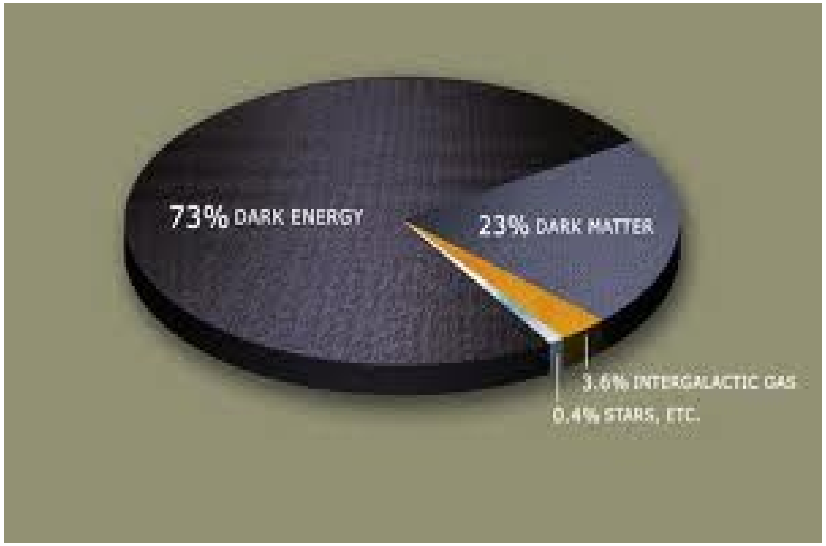
07/07/2012

Evidence for non-baryonic dark matter

Rotation curves in spiral galaxies



Lambda-CDM Model



Suggests 23% of the Universe consists of non-baryonic dark matter

What is dark matter?

A simple idea... assume dark matter belongs to a hidden sector exactly isomorphic to the standard model

$$\mathscr{L} = \mathscr{L}_{SM}(e, u, d, \gamma, \ldots) + \mathscr{L}_{SM}(e', u', d', \gamma', \ldots)$$

If left and right fields interchanged in the hidden sector, theory has exact parity symmetry, $x \to -x$

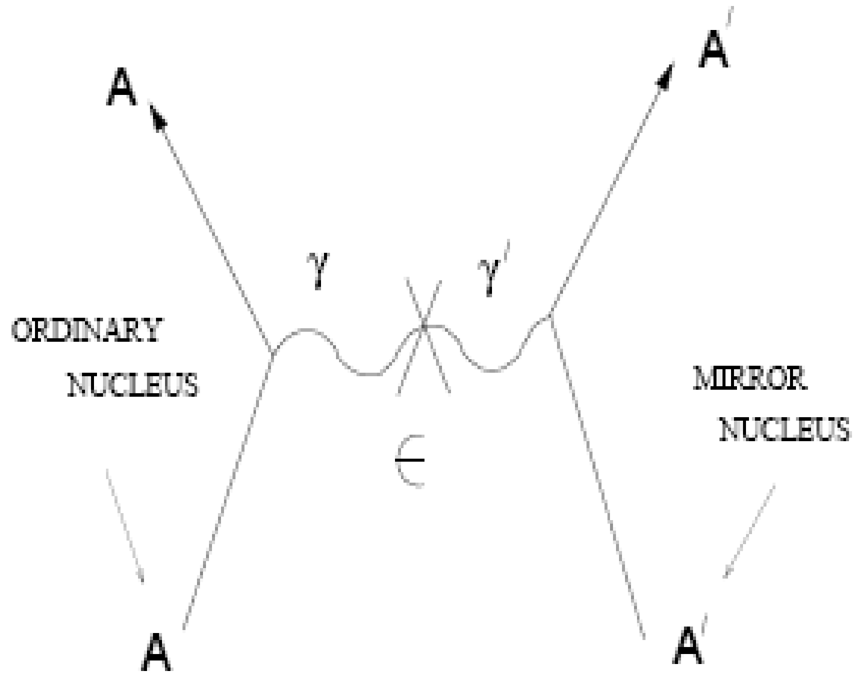
The e', H', He', … particles in the hidden (mirror) sector are stable and provide an interesting dark matter candidate.

The ordinary and mirror particles form two almost decoupled sectors which couple to each other via gravity and possibly by the renormalizable interactions:

$$\mathscr{L}_{mix} = \frac{\varepsilon}{2} F^{\mu\nu} F'_{\mu\nu} + \lambda \phi^\dagger \phi \phi'^\dagger \phi'$$

$$\frac{d\sigma}{dE_R} = \frac{\lambda}{E_R^2 v^2}$$

$$\lambda \equiv \frac{2\pi\epsilon^2 Z^2 Z'^2 \alpha^2}{m_A} F_A^2(qr_A) F_{A'}^2(qr_{A'})$$



Dark matter = mirror matter

Successful cosmology requires asymmetric initial conditions:

$$T' << T \quad \text{and} \quad n_{b'} = 5\, n_b$$

With such initial conditions the theory exactly mimics standard cold dark matter on large scales, i.e. successful LSS and CMB.

On smaller scales mirror dark matter is radically different to standard cold dark matter because it is self interacting and dissipative.

What about on small scales?

Observations suggest that galactic halo is a pressure supported plasma consisting of e', H', He', O', Fe',...

Such a plasma would radiatively cool unless heat source exists.

Ordinary supernova can supply the required energy if the kinetic mixing has strength :

$$\epsilon \sim 10^{-9}$$

~ half of supernova core collapse energy goes into mirror e'

Importantly, if kinetic mixing exists can detect mirror particles in experiments

DAMA/NaI and DAMA/Libra experiments

First claim of direct detection of dark matter! More than 10 years already.

ROM2F/2008/07
April 2008

First results from DAMA/LIBRA and the combined results with DAMA/NaI

R. Bernabei [a,b], P. Belli [b], F. Cappella [c,d], R. Cerulli [e], C.J. Dai [f], A. d'Angelo [c,d], H.L. He [f], A. Incicchitti [d], H.H. Kuang [f], J.M. Ma [f], F. Montecchia [a,b], F. Nozzoli [a,b], D. Prosperi [c,d], X.D. Sheng [f], Z.P. Ye [f,g]

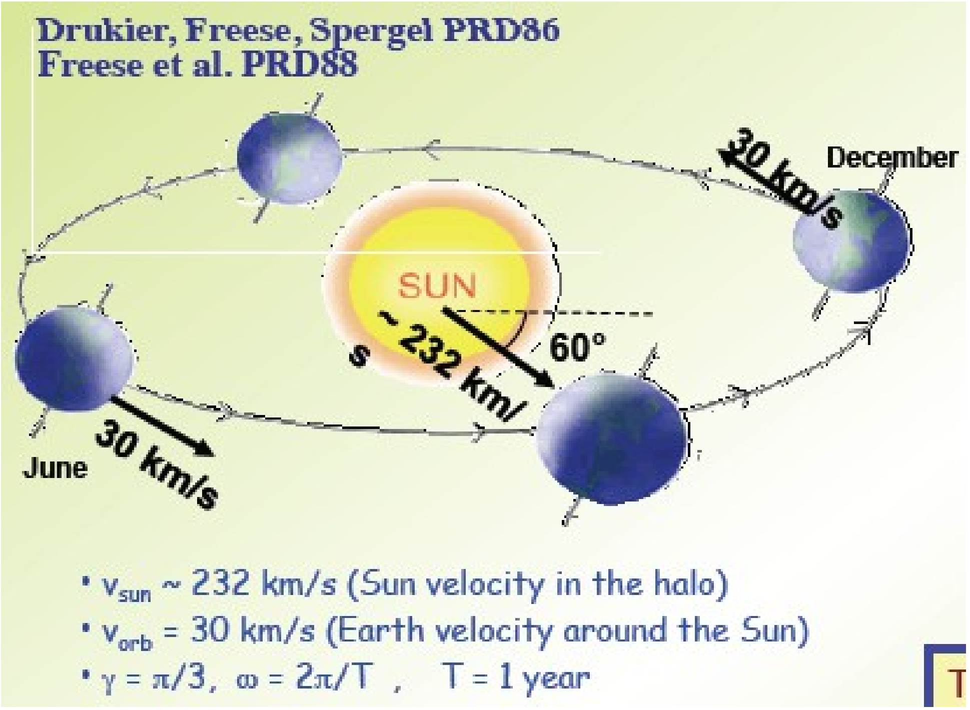
[a] *Dip. di Fisica, Università di Roma "Tor Vergata", I-00133 Rome, Italy*
[b] *INFN, sez. Roma "Tor Vergata", I-00133 Rome, Italy*
[c] *Dip. di Fisica, Università di Roma "La Sapienza", I-00185 Rome, Italy*
[d] *INFN, sez. Roma, I-00185 Rome, Italy*
[e] *Laboratori Nazionali del Gran Sasso, I.N.F.N., Assergi, Italy*
[f] *IHEP, Chinese Academy, P.O. Box 918/3, Beijing 100039, China*
[g] *University of Jing Gangshan, Jiangxi, China*

DAMA team have found evidence for dark matter with DAMA/NaI (100 kg NaI target) 1997-2003 and confirmed with more precision by DAMA/Libra (250 kg NaI target) 2003-2012

DAMA/NaI and DAMA/Libra experiments

Evidence from direct detection experiments, especially DAMA/LIBRA annual modulation signal

$$R(v_E) = R(v_\odot) + \left(\frac{\partial R}{\partial v_E}\right)_{v_\odot} \Delta v_E \cos\omega(t - t_0)$$

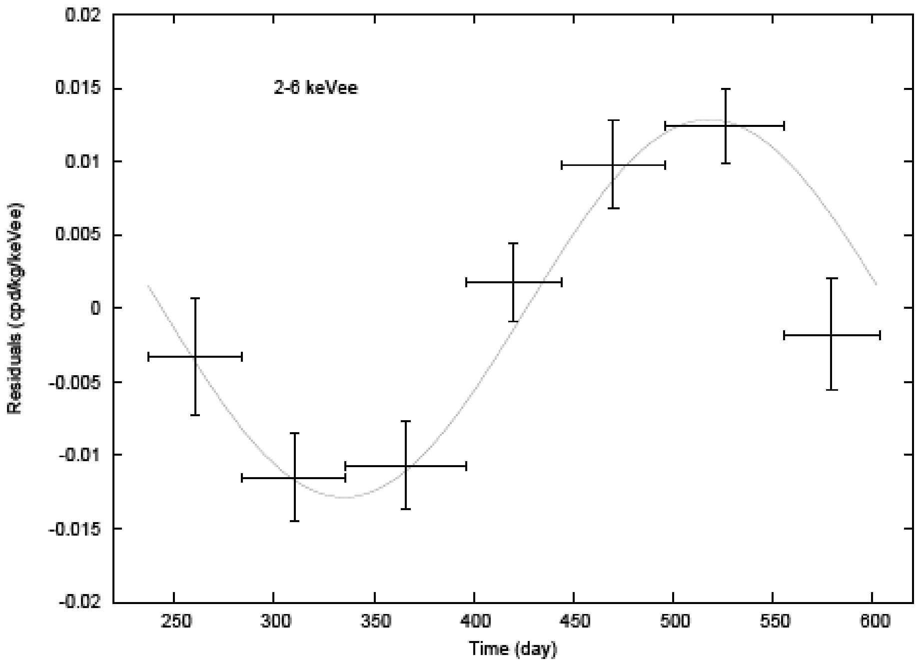


Phase and Period of modulation are predicted! t_0 = 152 (June 2), T = 1 year.

$$\begin{aligned} T &= 0.999 \pm 0.002 \text{ year} \\ t_0 &= 146 \pm 7 \text{ day.} \end{aligned}$$

DAMA/NaI and DAMA/Libra experiments

$$R(v_E) = R(v_\odot) + \left(\frac{\partial R}{\partial v_E}\right)_{v_\odot} \Delta v_E \cos\omega(t - t_0)$$



Rates are measured as function of nuclear recoil energy, E_R

Astro & Particle Physics

$$\frac{dR}{dE_R} = N_T n_{A'} \int \frac{d\sigma}{dE_R} \frac{f_{A'}(\mathbf{v}, \mathbf{v}_E)}{k} |\mathbf{v}| d^3v$$

Particle Physics

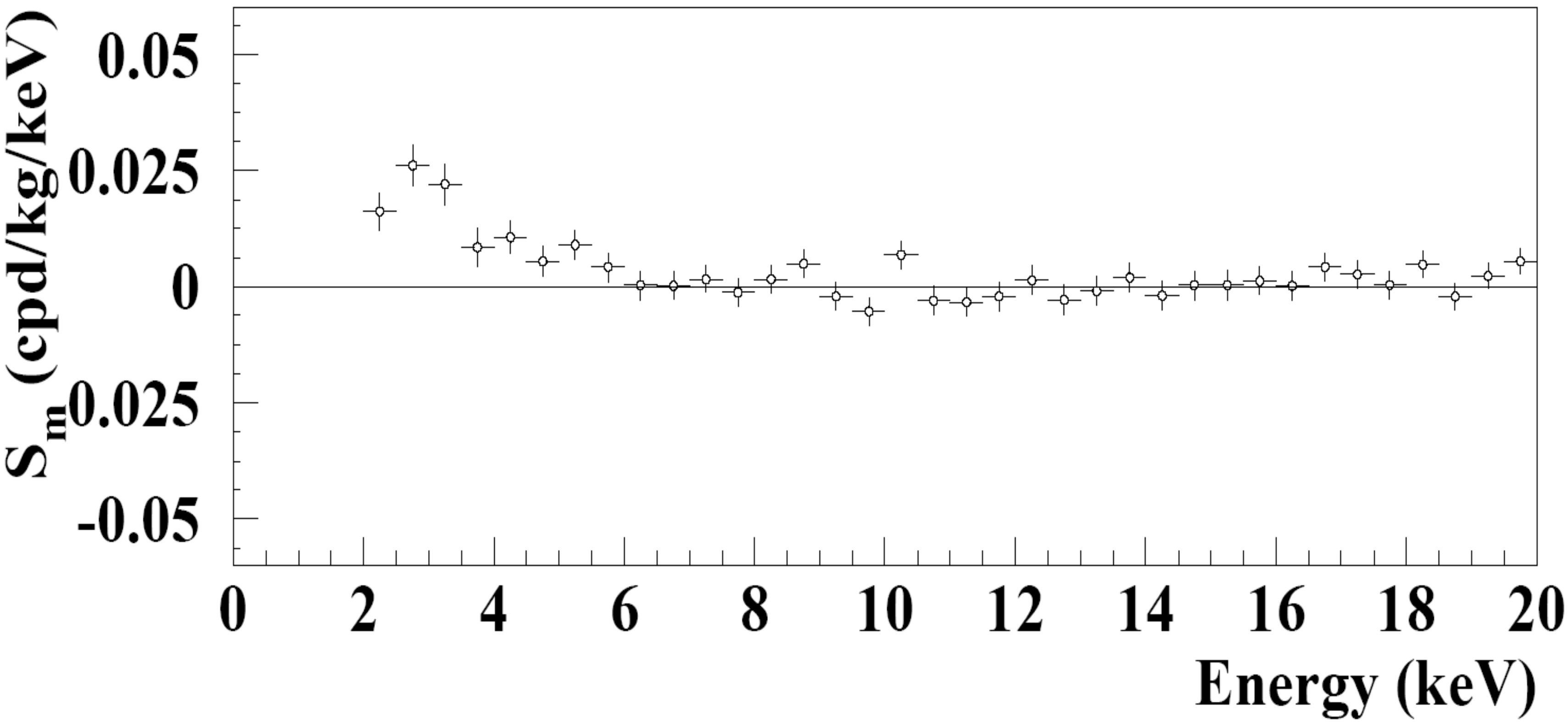
Energy distribution of the modulation amplitudes

$$R(t) = S_0 + S_m \cos[\omega(t - t_0)]$$

here $T=2\pi/\omega=1$ yr and $t_0= 152.5$ day

DAMA/NaI (7 years) + DAMA/LIBRA (6 years)

total exposure: 425428 kg×day ≈1.17 ton×yr



Modulation is present in the 2-6 keV energy interval.

A feature of DAMA is its low energy threshold

The CoGeNT and CRESST experiments also have low energy thresholds and they also see a possible dark matter signal.

Many sensitive, but higher threshold experiments such as XENON100 and CDMS have yet to find any dark matter signal.

Can mirror dark matter explain these results?

Kinetic mixing interaction, with $\epsilon \sim 10^{-9}$ means ordinary and mirror particles can interact with each other and can therefore be detected!

$$\frac{dR}{dE_R} = N_T n_{A'} \int \frac{d\sigma}{dE_R} \frac{f_{A'}(\mathbf{v}, \mathbf{v}_E)}{k} |\mathbf{v}| d^3 v$$

Rate depends on halo distribution function

$$\begin{aligned} f[i] &= e^{-\frac{1}{2} m_i v^2 / T} \\ &= e^{-v^2 / v_0^2[i]} \end{aligned}$$

Temperature can be determined from condition of hydrostatic equilibrium

$$\frac{dP}{dr} = -\rho g$$

$$P = \sum n_i T, \ \rho = \sum m_i n_i, \ g = \frac{G}{r^2} \int^r \rho \, dV = \frac{v_{rot}^2}{r}$$

Solving this equation leads to $T = \frac{1}{2}\overline{m}v_{rot}^2$

Galactic rotation velocity

And hence $v_0^2[i] = v_{rot}^2 \frac{\overline{m}}{m_i}$

Mean mass of particles in halo

The key point is that heavy particles have narrow velocity dispersion

If $m_i \gg \overline{m}$, then $v_0^2[i] \ll v_{rot}^2$

This can help explain why DAMA sees a signal and higher threshold experiments such as CDMS and XENON100 do not!

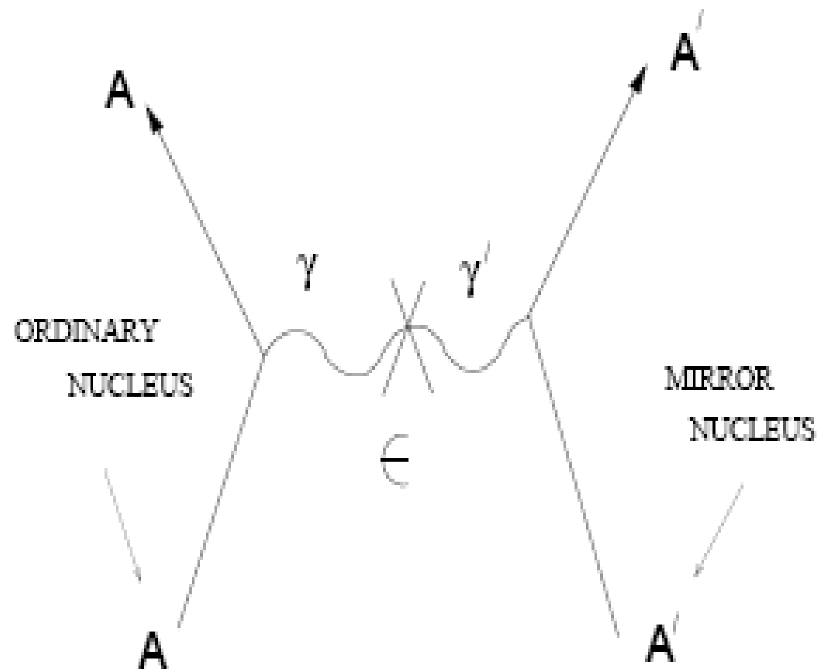
$$\frac{dR}{dE_R} = N_T n_{A'} \int \frac{d\sigma}{dE_R} \frac{f_{A'}(\mathbf{v}, \mathbf{v}_E)}{k} |\mathbf{v}| d^3 v$$

Rate also depends on the cross section. For mirror matter, ordinary and mirror particles interact via kinetic mixing induced Rutherford scattering.

$$\mathscr{L}_{mix} = \frac{\varepsilon}{2} F^{\mu\nu} F'_{\mu\nu} + \lambda \phi^\dagger \phi \phi'^\dagger \phi'$$

$$\frac{d\sigma}{dE_R} = \frac{\lambda}{E_R^2 v^2}$$

$$\lambda \equiv \frac{2\pi\epsilon^2 Z^2 Z'^2 \alpha^2}{m_A} F_A^2(qr_A) F_{A'}^2(qr_A$$



DAMA experiment measures annual modulation

$$R(v_E) = R(v_\odot) + \left(\frac{\partial R}{\partial v_E}\right)_{v_\odot} \Delta v_E \cos\omega(t - t_0)$$

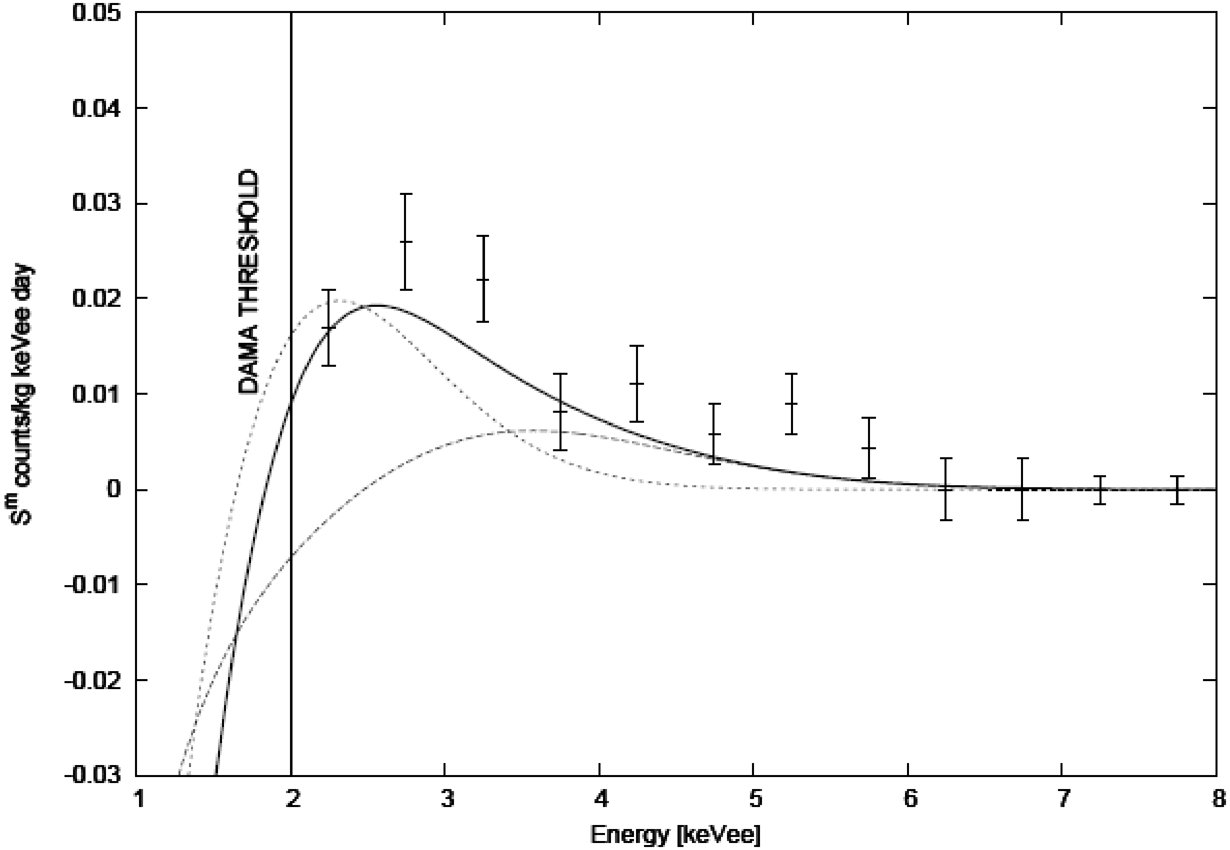
Mirror dark matter can fit the energy dependence of the DAMA modulation

Shown is fit for an example:

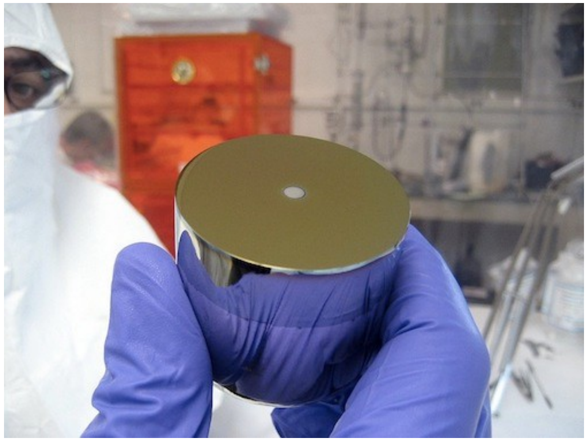
$$A' = \mathrm{Fe}'$$

$$v_{rot} = 200\ \mathrm{km/s},$$

$$\epsilon\sqrt{\xi_{Fe'}} = 2.2 \times 10^{-10}$$



The CoGeNT collaboration designed a detector with low energy threshold to check DAMA



P-type germanium contact detector

Results from a Search for Light-Mass Dark Matter with a P-type Point Contact Germanium Detector

C.E. Aalseth,[1] P.S. Barbeau,[2] N.S. Bowden,[3] B. Cabrera-Palmer,[4] J. Colaresi,[5] J.I. Collar*,[2] S. Dazeley,[3] P. de Lurgio,[6] G. Drake,[6] J.E. Fast,[1] N. Fields,[2] C.H. Greenberg,[2] T.W. Hossbach,[1,2] M.E. Keillor,[1] J.D. Kephart,[1] M.G. Marino,[7] H.S. Miley,[1] M.L. Miller,[7] J.L. Orrell,[1] D.C. Radford,[8] D. Reyna,[4] R.G.H. Robertson,[7] R.L. Talaga,[6] O. Tench,[5] T.D. Van Wechel,[7] J.F. Wilkerson,[7,9] and K.M. Yocum[5]

(CoGeNT Collaboration)

[1]*Pacific Northwest National Laboratory, Richland, WA 99352, USA*
[2]*Kavli Institute for Cosmological Physics and Enrico Fermi Institute, University of Chicago, Chicago, IL 60637, USA*
[3]*Lawrence Livermore National Laboratory, Livermore, CA 94550, USA*
[4]*Sandia National Laboratories, Livermore, CA 94550, USA*
[5]*CANBERRA Industries, Meriden, CT 06450, USA*
[6]*Argonne National Laboratory, Argonne, IL 60439, USA*
[7]*Center for Experimental Nuclear Physics and Astrophysics and Department of Physics, University of Washington, Seattle, WA 98195, USA*
[8]*Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA*
[9]*Department of Physics and Astronomy, University of North Carolina, NC 27599, USA*

We report on several features present in the energy spectrum from an ultra low-noise germanium detector operated at 2,100 m.w.e. By implementing a new technique able to reject surface events, a number of cosmogenic peaks can be observed for the first time. We discuss several possible causes for an irreducible excess of bulk-like events below 3 keVee, including a dark matter candidate common to the DAMA/LIBRA annual modulation effect, the hint of a signal in CDMS, and phenomenological predictions. Improved constraints are placed on a cosmological origin for the DAMA/LIBRA effect.

Feb 2010

Search for an Annual Modulation in a P-type Point Contact Germanium Dark Matter Detector

C.E. Aalseth,[1] P.S. Barbeau,[2,*] J. Colaresi,[3] J.I. Collar,[2,†] J. Diaz Leon,[4] J.E. Fast,[1] N. Fields,[2] T.W. Hossbach,[1,2] M.E. Keillor,[1] J.D. Kephart,[1] A. Knecht,[4] M.G. Marino,[4,‡] H.S. Miley,[1] M.L. Miller,[4] J.L. Orrell,[1] D.C. Radford,[5] J.F. Wilkerson,[6] and K.M. Yocum[3]

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[5]*Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA*
[6]*Department of Physics and Astronomy, University of North Carolina, NC 27599, USA*

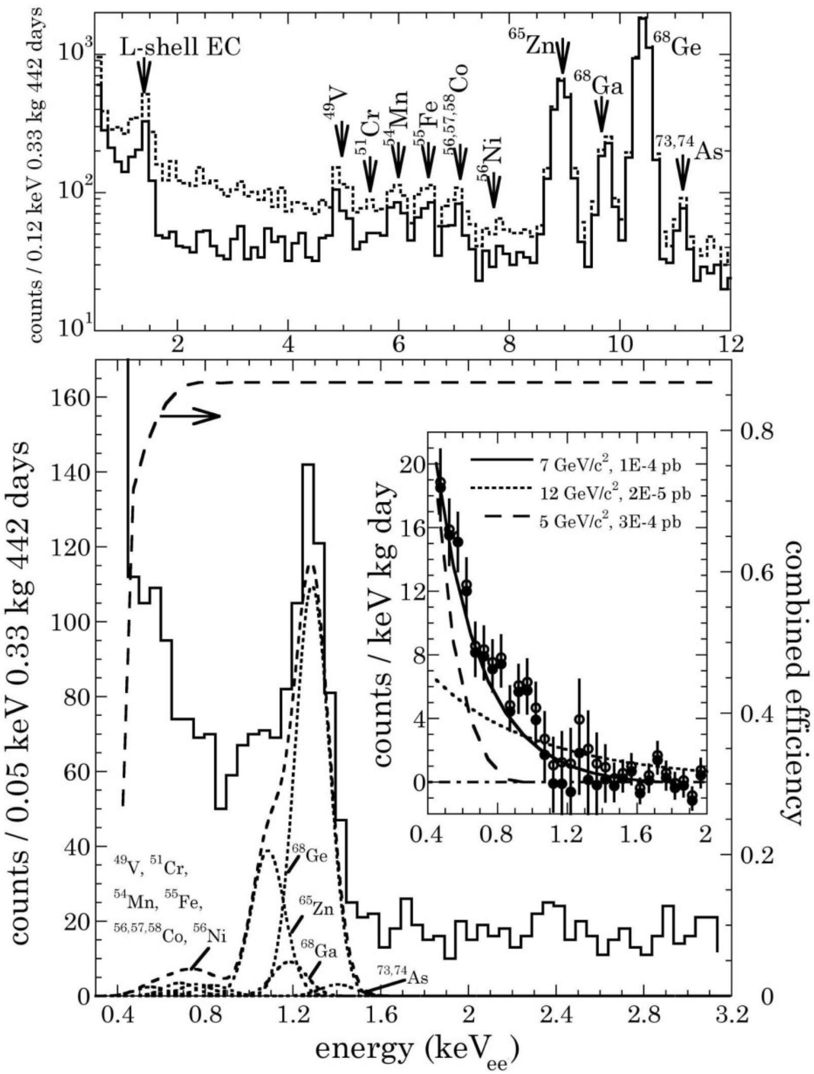
Fifteen months of cumulative CoGeNT data are examined for indications of an annual modulation, a predicted signature of Weakly Interacting Massive Particle (WIMP) interactions. Presently available data support the presence of a modulated component of unknown origin, with parameters *prima facie* compatible with a galactic halo composed of light-mass WIMPs. Unoptimized estimators yield a statistical significance for a modulation of $\sim 2.8\sigma$, limited by the short exposure.

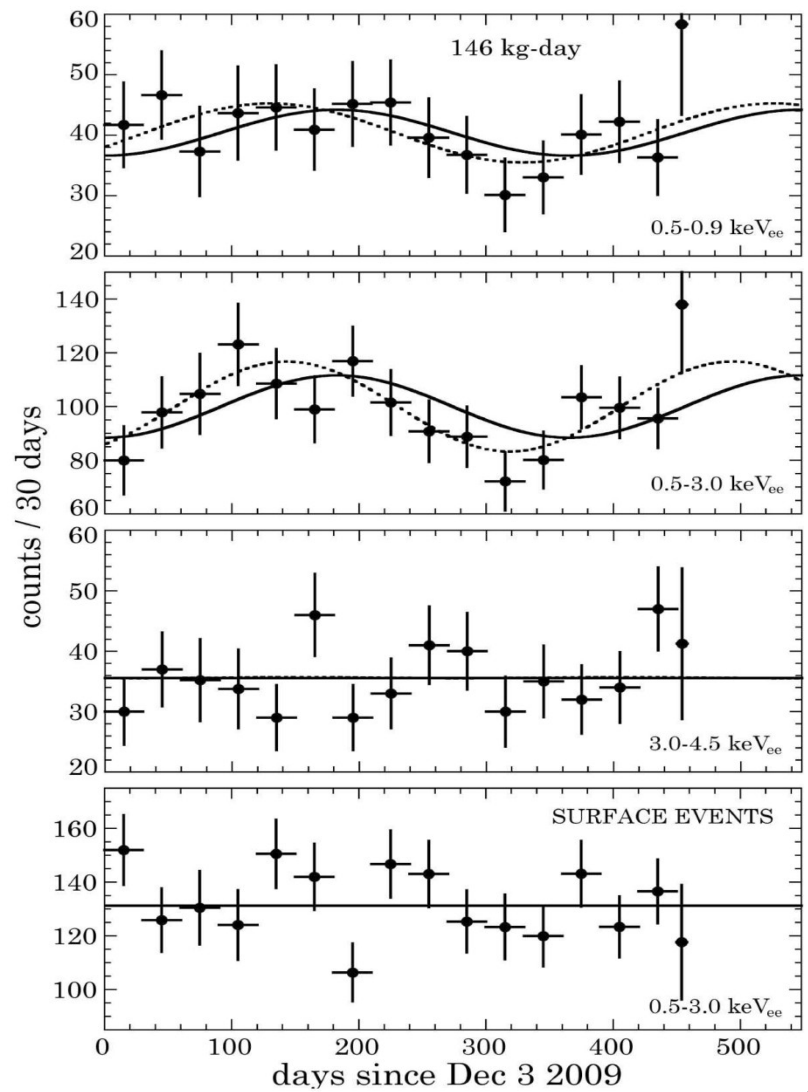
PACS numbers: 85.30.-z, 95.35.+d, 95.55.Vj, 14.80.Mz

June 2011

CoGeNT total rate from 442 days

Hint of annual modulation!





CoGeNT spectrum quite uncertain due to surface event correction.

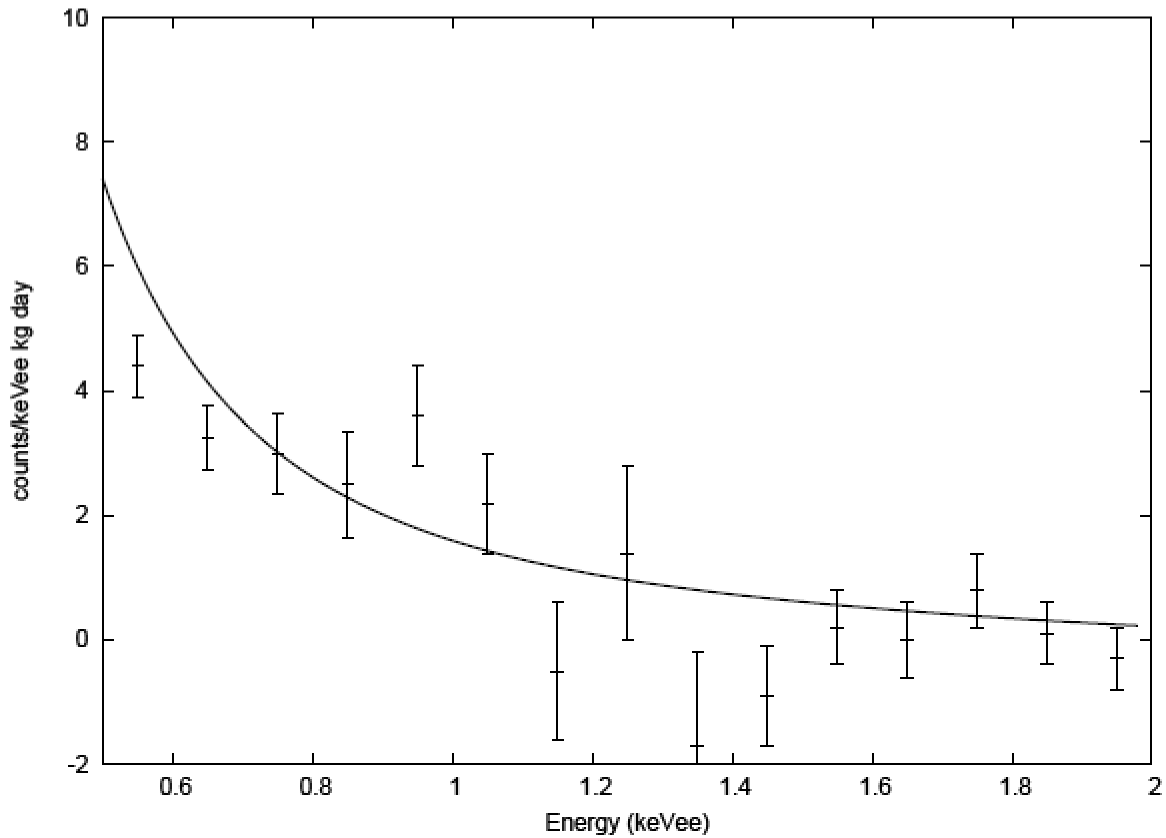
Mirror dark matter can fit the energy dependence of the CoGeNT spectrum

Shown is fit for an example:

$$A' = \mathrm{Fe}'$$

$$v_{rot} = 200 \text{ km/s},$$

$$\epsilon\sqrt{\xi_{Fe'}} = 2.2 \times 10^{-10}$$



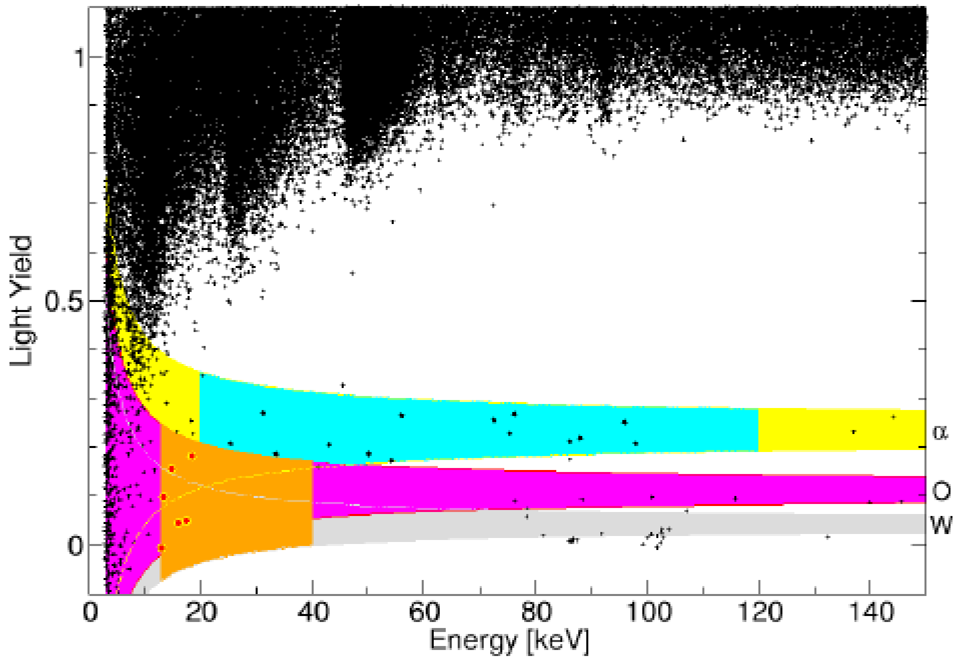
CRESST

Results from 730 kg days of the CRESST-II Dark Matter Search

G. Angloher[1], M. Bauer[2], I. Bavykina[1], A. Bento[1,5], C. Bucci[3], C. Ciemniak[4], G. Deuter[2], F. von Feilitzsch[4], D. Hauff[1], P. Huff[1], C. Isaila[4], J. Jochum[2], M. Kiefer[1], M. Kimmerle[2], J.-C. Lanfranchi[4], F. Petricca[1], S. Pfister[4], W. Potzel[4], F. Pröbst[1a], F. Reindl[1], S. Roth[4], K. Rottler[2], C. Sailer[2], K. Schäffner[1], J. Schmaler[1b], S. Scholl[2], W. Seidel[1], M. v. Sivers[4], L. Stodolsky[1], C. Strandhagen[2], R. Strauß[4], A. Tanzke[1], I. Usherov[2], S. Wawoczny[4], M. Willers[4], and A. Zöller[4]

ArXiv:1109.0702, 4 September 2011

CRESST detector composed of O, Ca and W. Sensitive to light dark matter via interactions on O and Ca.



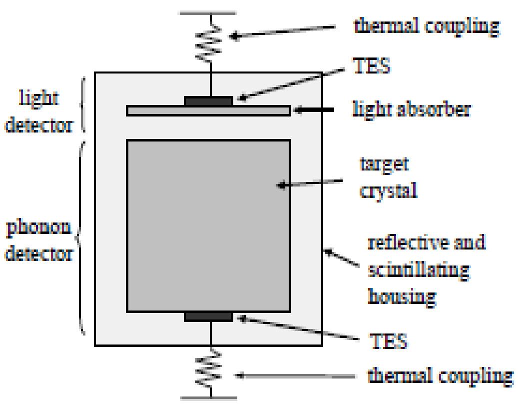


Fig. 2. Schematic drawing of a CRESST detector module, consisting of the target crystal and an independent light detector. Both are read out by transition edge sensors (TES) and are enclosed in a common reflective and scintillating housing.

CRESST

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CRESST found 67 events from 730 kg-days of exposure. However, at least half of these are from backgrounds. Nevertheless there is tentative evidence for light dark matter from rising event rate at low recoil energies.

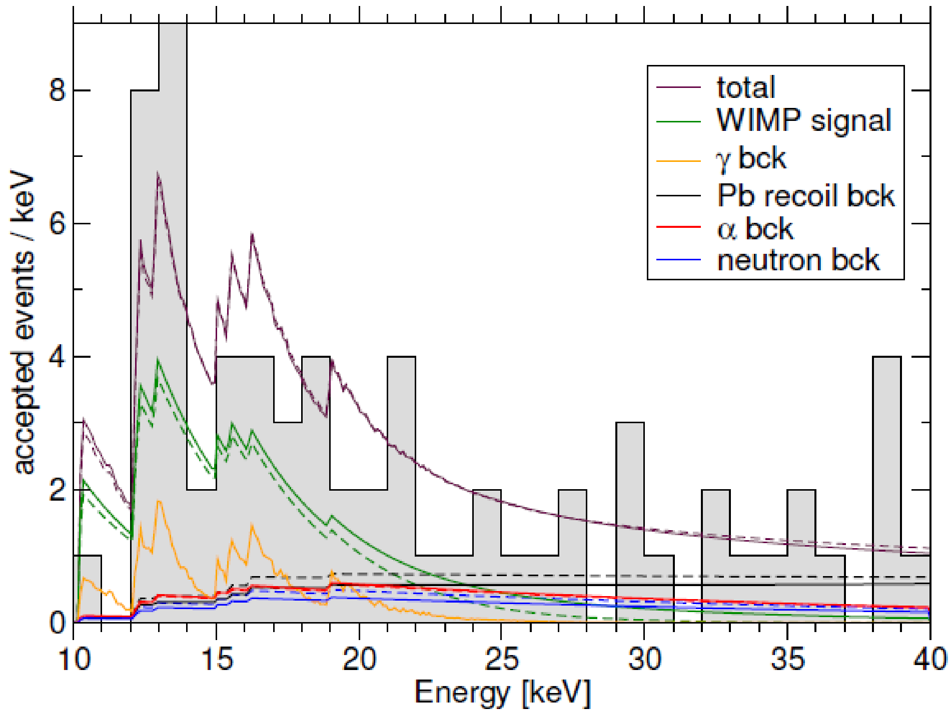


Fig. 11. (Color online) Energy spectrum of the accepted events from all detector modules, together with the expected contributions from the considered backgrounds and a WIMP signal, as inferred from the likelihood fit. The solid and dashed lines correspond to the fit results M1 and M2, respectively.

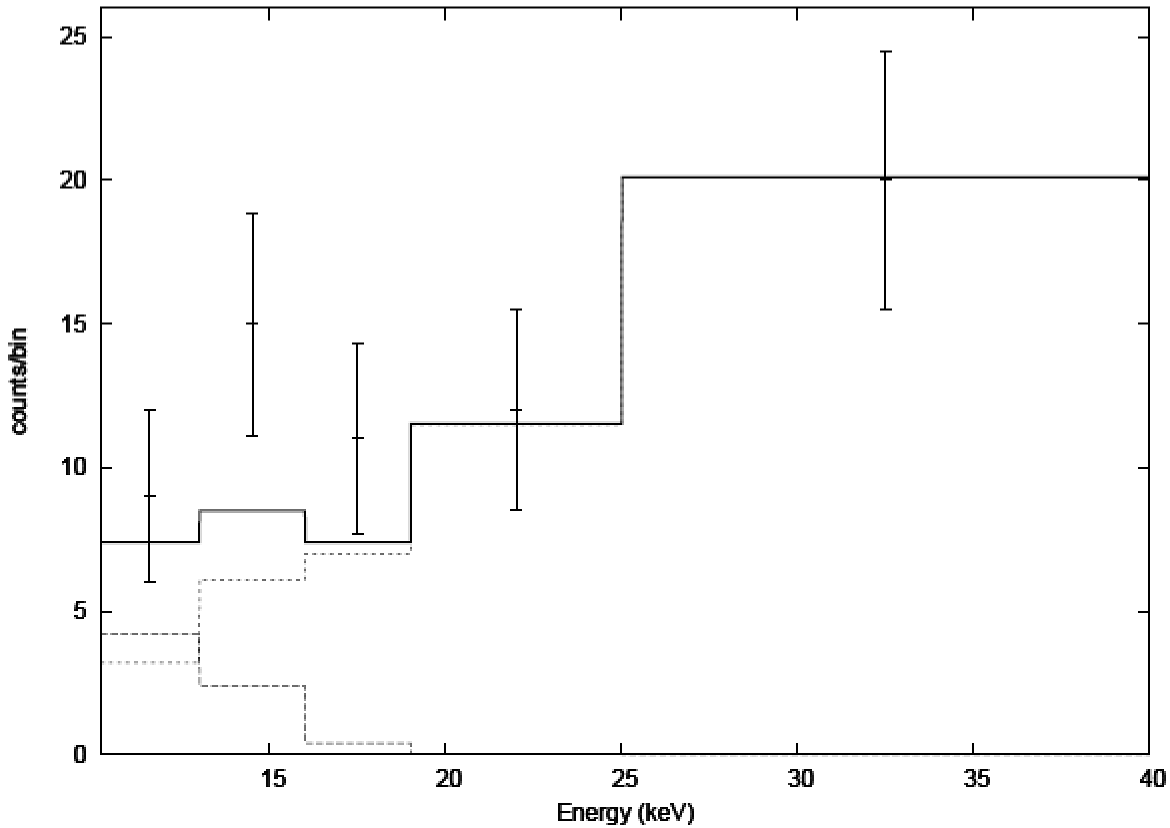
Mirror dark matter can fit the CRESST-II spectrum.

Shown is fit for an example:

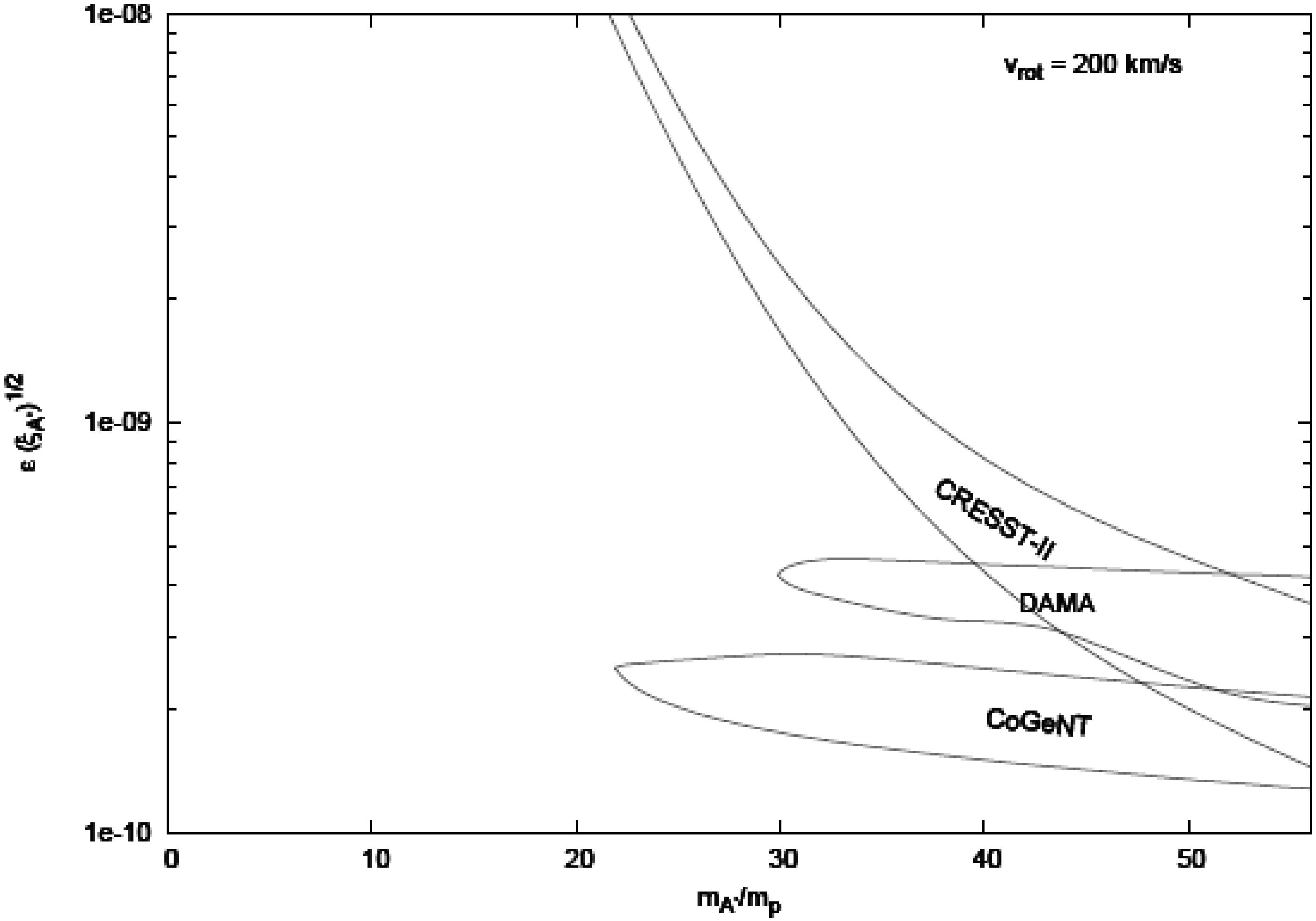
$$A' = \mathrm{Fe}'$$

$$v_{rot} = 200 \text{ km/s},$$

$$\epsilon\sqrt{\xi_{Fe'}} = 2.2 \times 10^{-10}$$



Combined fit of DAMA, CoGeNT and CRESST-II



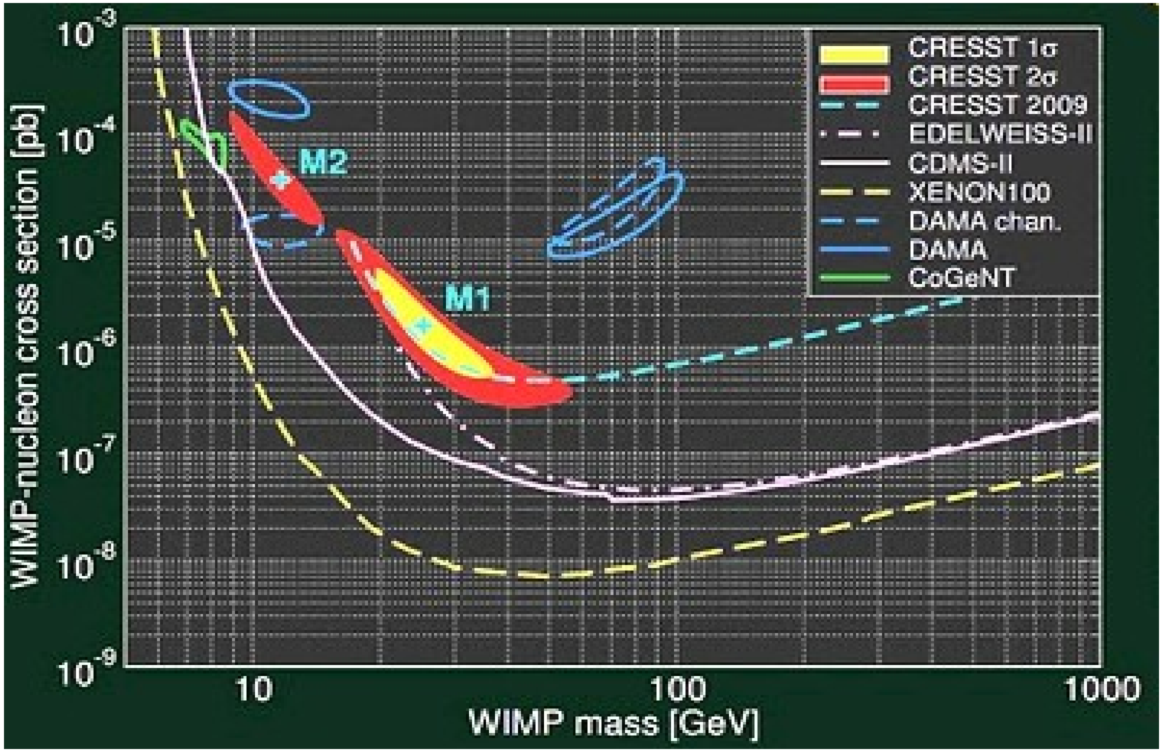
Mirror dark matter different to standard WIMP models

1) Mirror dark matter is necessarily light < 52 GeV

2) Mirror dark matter interacts via Rutherford scattering, rather than contact interactions

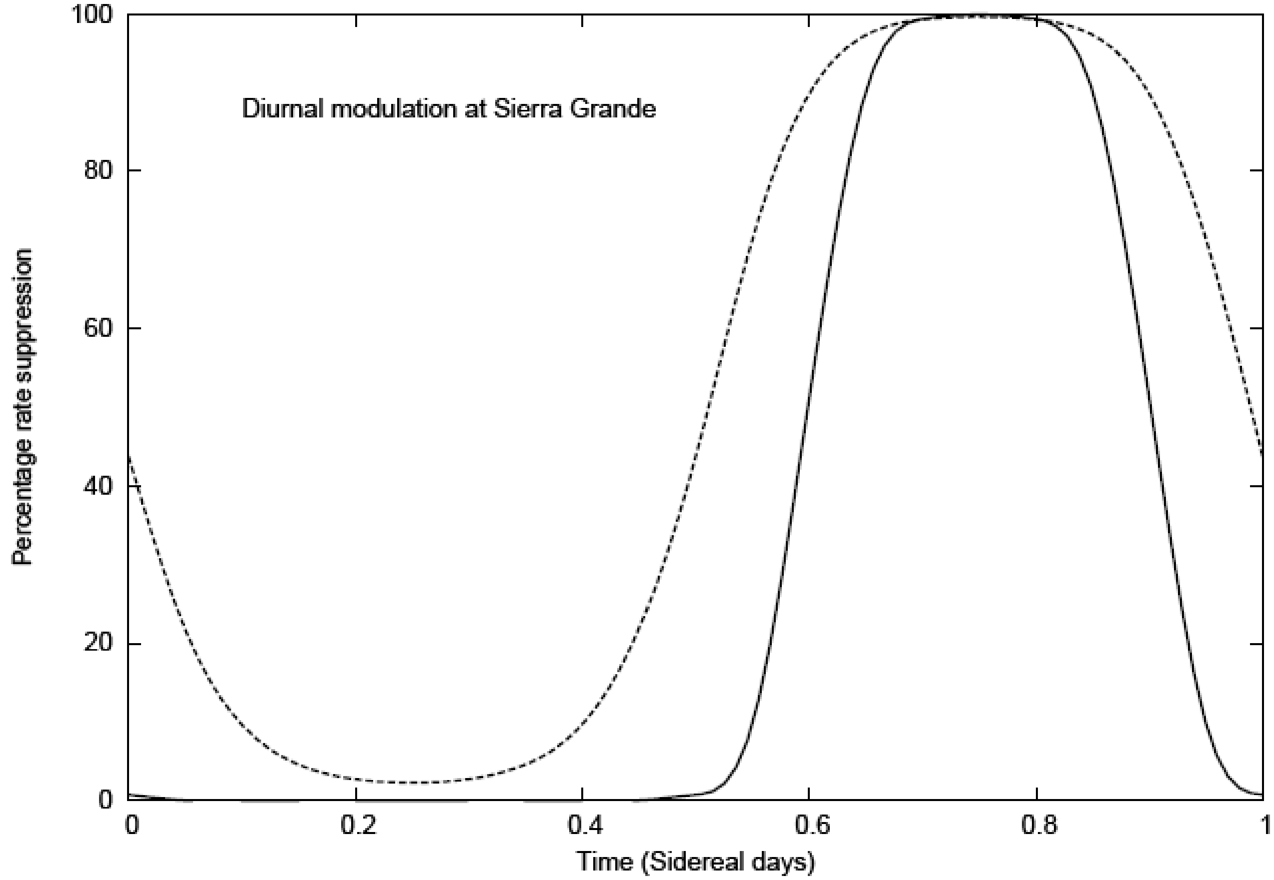
3) Mirror dark matter is multi-component which leads to narrow velocity dispersion.

Parameter space in standard wimp model

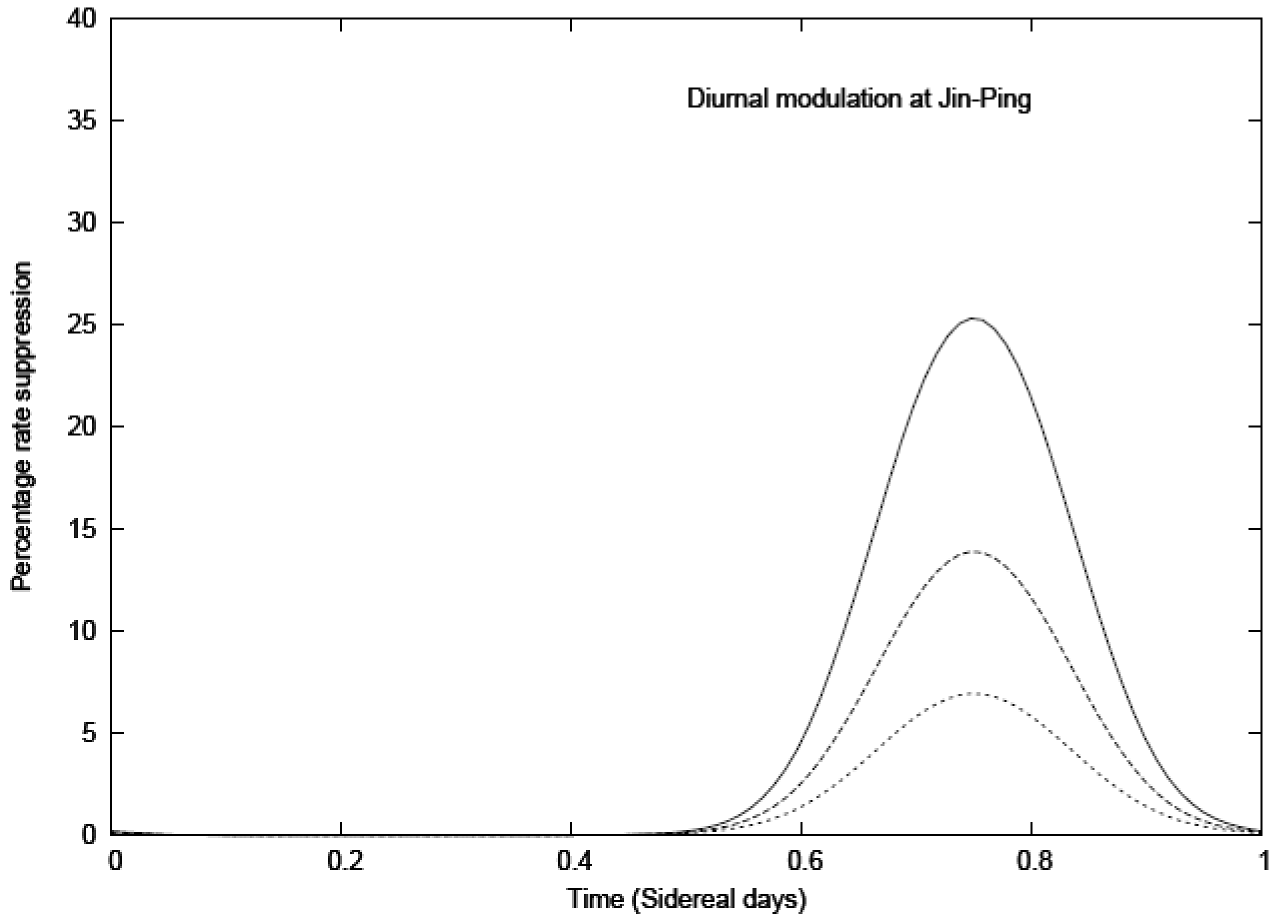


Diurnal variation

Mirror dark matter, and self interacting dark matter in general, predicts large diurnal variation for detectors located in Southern Hemisphere.



For northern hemisphere, diurnal variation is more challenging, but might possibly be seen in Jin-Ping



Conclusions

Evidence for non-baryonic dark matter from rotation curves in galaxies, and precision cosmology.

DAMA, CoGeNT and perhaps CRESST-II experiments may have actually detected galactic dark matter!

These experiments can be explained if dark matter = mirror matter (or possibly a more generic hidden sector).

This explanation will be tested more stringently during the next few years as more data is collected. So stay tuned!