The Case for a dark matter detector in Australia

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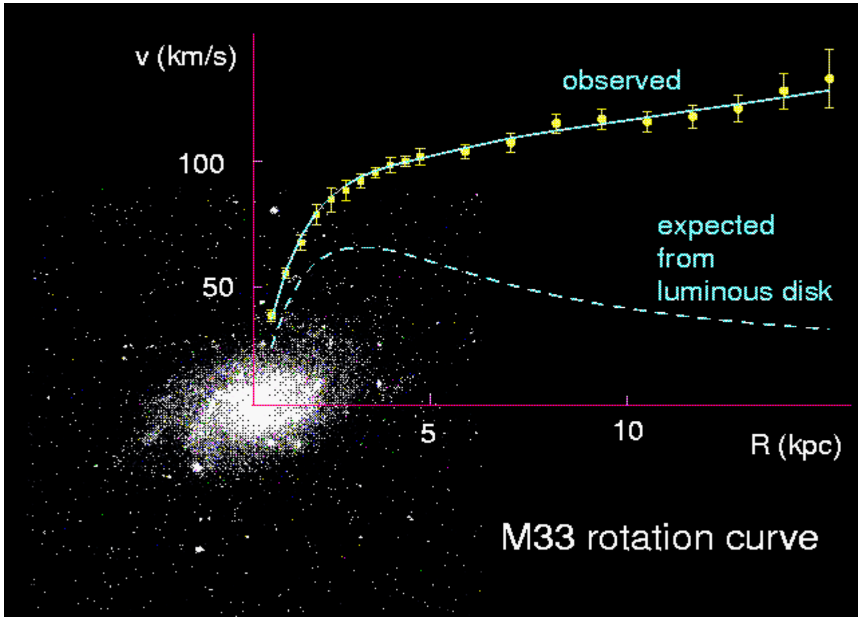
Talk at Italy-Australia Symposium

12/07/2012

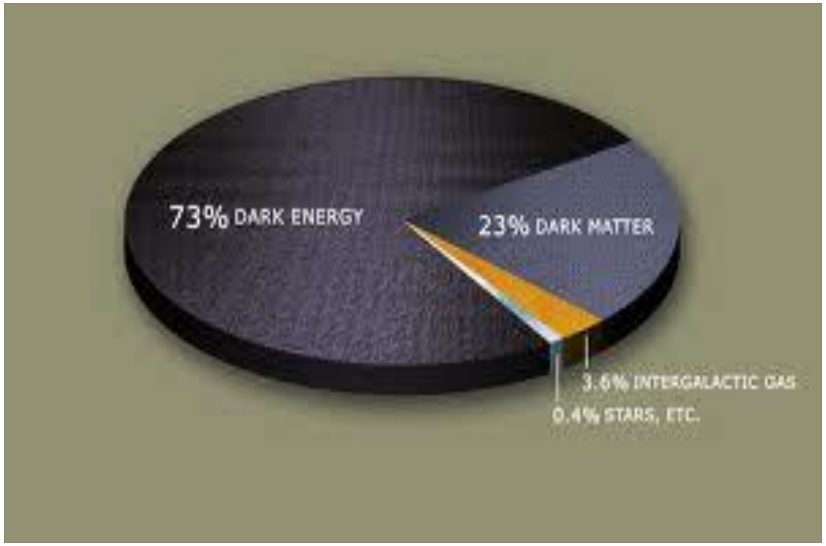
Evidence for non-baryonic dark matter

Rotation curves in spiral galaxies



Lambda-CDM Model

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



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]

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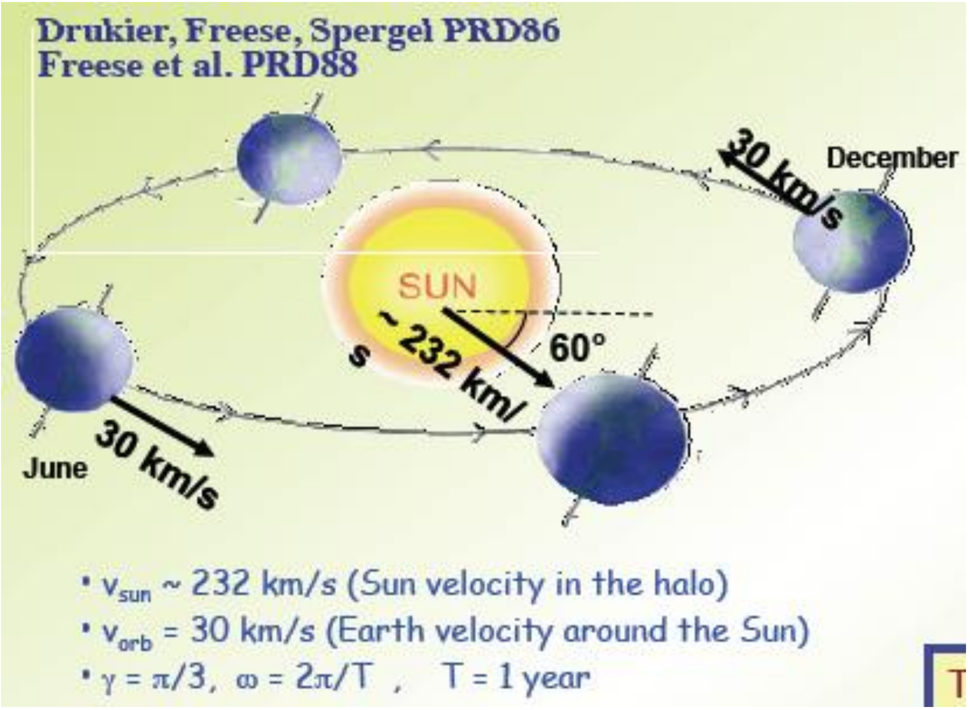
DAMA team have found evidence for dark matter with DAMA/NaI (100 kg NaI target) 1997-2003 and confirmed with more precision by DAMA/Libra (250 kg NaI target) 2003-2012

DAMA/NaI and DAMA/Libra experiments

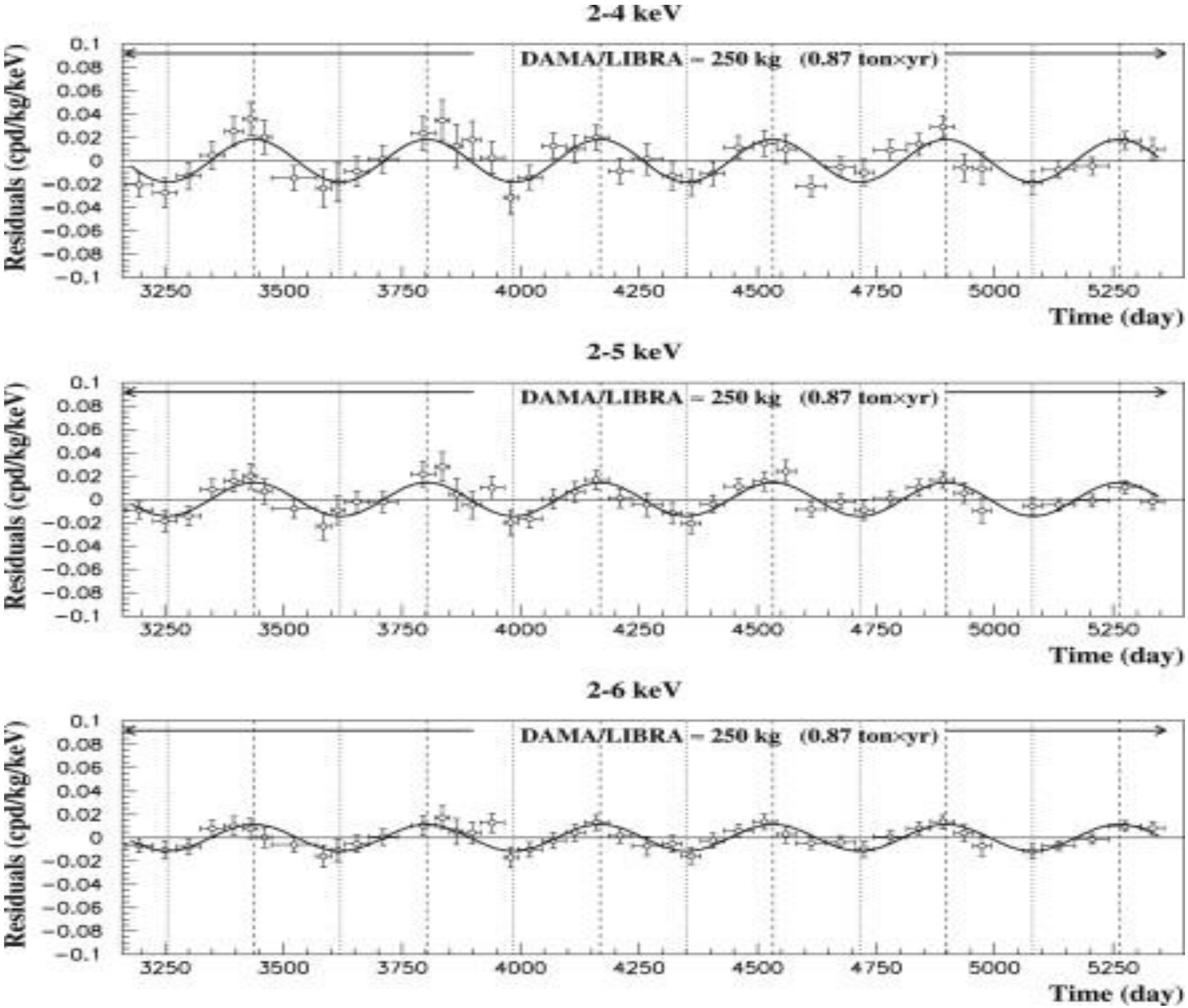
Evidence from direct detection experiments, especially DAMA/LIBRA annual modulation signal

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



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

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


2-4 keV
DAMA/LIBRA ≈ 250 kg (0.87 ton×yr)
Residuals (cpd/kg/keV)
Time (day)
2-5 keV
DAMA/LIBRA ≈ 250 kg (0.87 ton×yr)
Residuals (cpd/kg/keV)
Time (day)
2-6 keV
DAMA/LIBRA ≈ 250 kg (0.87 ton×yr)
Residuals (cpd/kg/keV)
Time (day)

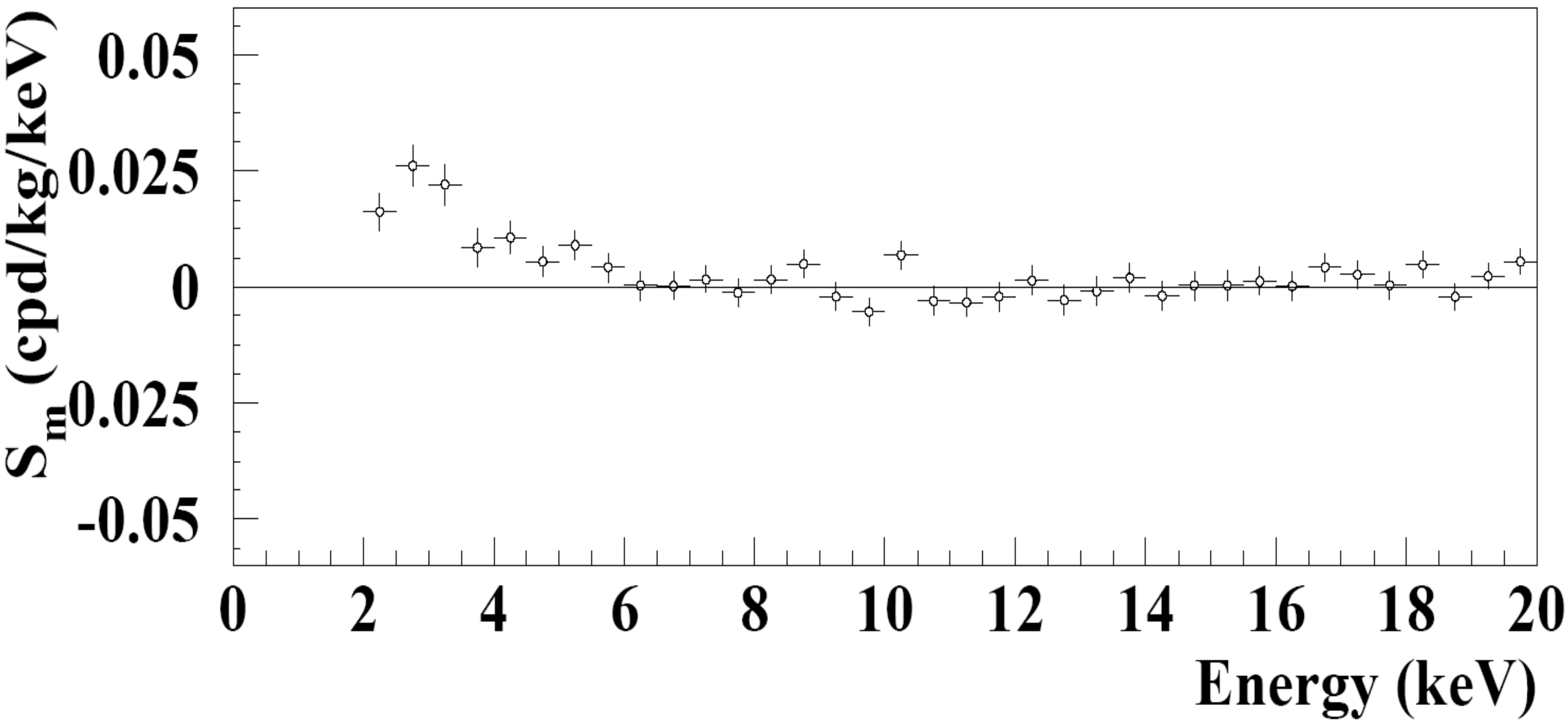
Energy distribution of the modulation amplitudes

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

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

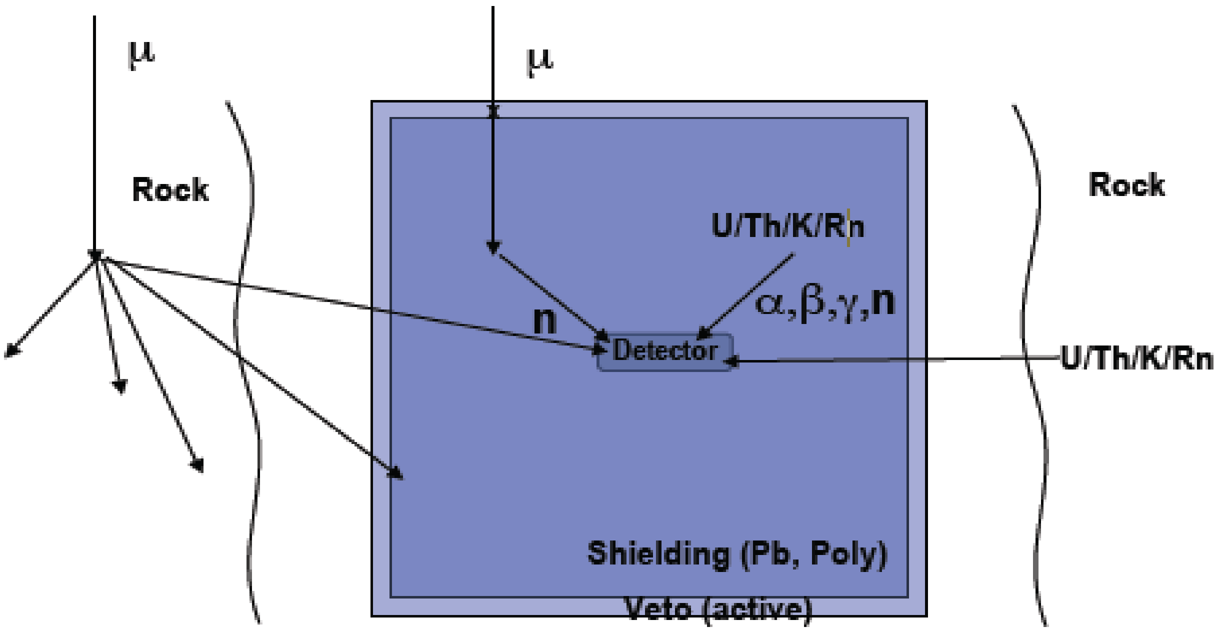
DAMA/NaI (7 years) + DAMA/LIBRA (6 years)

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



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

Backgrounds for Direct Detection Experiments



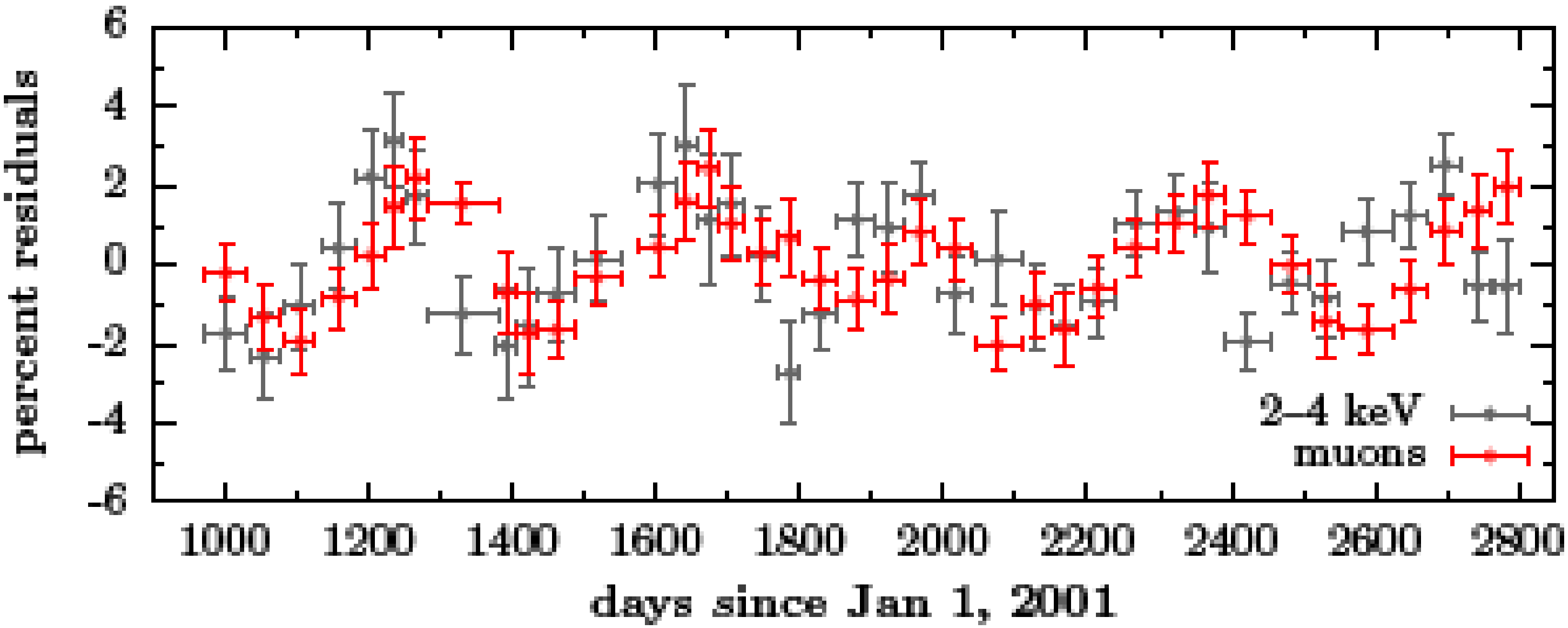
Pb shielding to reduce EM backgrounds from radioactivity

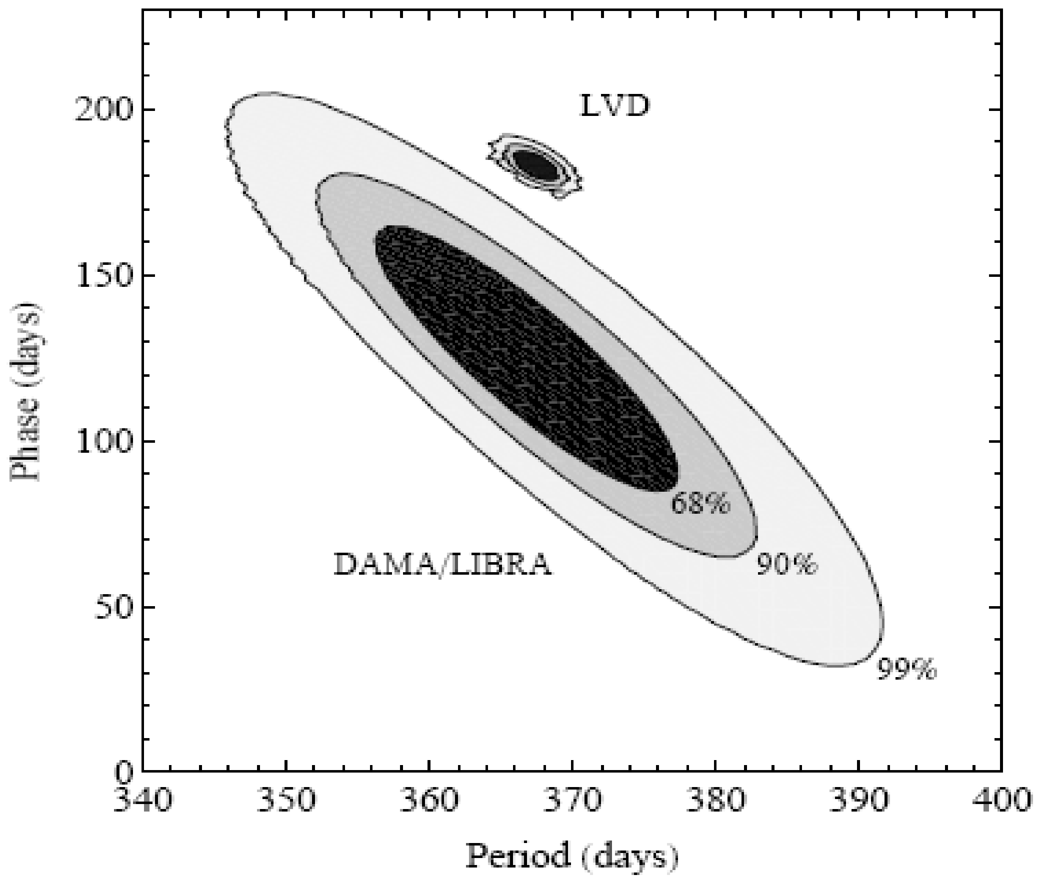
Polyethylene contains hydrogen needed to moderate neutrons from radioactivity

Depth is necessary to reduce flux of fast neutrons from cosmic ray interactions (although active veto may partially substitute for depth)

Can backgrounds possibly give annual modulation?

Only possibility appears to be muon flux which is known to modulate annually, due to variations in the atmosphere due to temperature .. summer/winter





Chang et al, ArXiv: 1111.4222

Clearly, phase doesn't quite work out.

Also estimates of DAMA background rate from muons, reviewed in arXiv: 1202. 4179, are more than 2 orders of magnitude too small to account for DAMA signal.

Nevertheless, it would be extremely important to check DAMA signal in southern hemisphere.

If the DAMA annual modulation signal were somehow due to background, it is reasonable to expect that it would have different phase for a detector in the southern hemisphere.

There is another reason to do dark matter experiments in the Southern Hemisphere. It turns out that the southern hemisphere is much more sensitive to diurnal signal.

Lots of dark matter direct detection experiments, but NONE in the Southern Hemisphere !

What is dark matter?

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

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

RF, H. Lew and R. R. Volkas, PLB,91

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

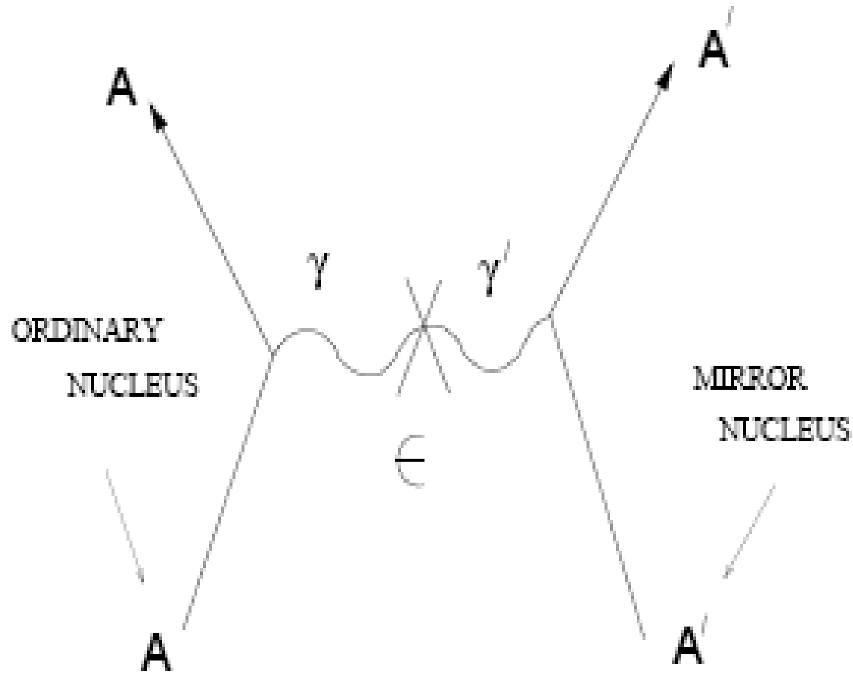
The e', H', He', ... particles in the hidden (mirror) sector are stable and provide an interesting dark matter candidate.

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

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

Mean mass of particles in halo

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

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!

DAMA experiment measures annual modulation

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

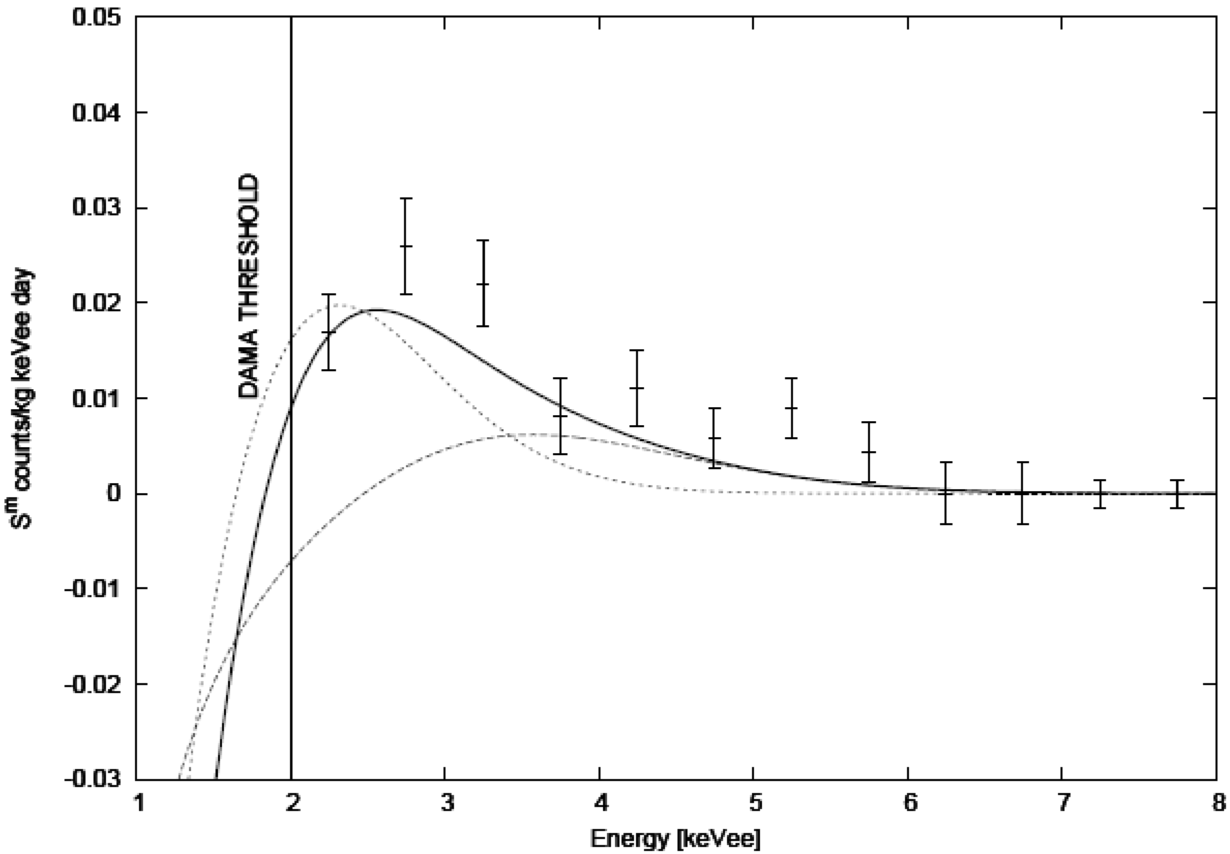
Mirror dark matter can fit the energy dependence of the DAMA modulation

Shown is fit for an example:

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

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

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



CoGeNT spectrum quite uncertain due to surface event correction.

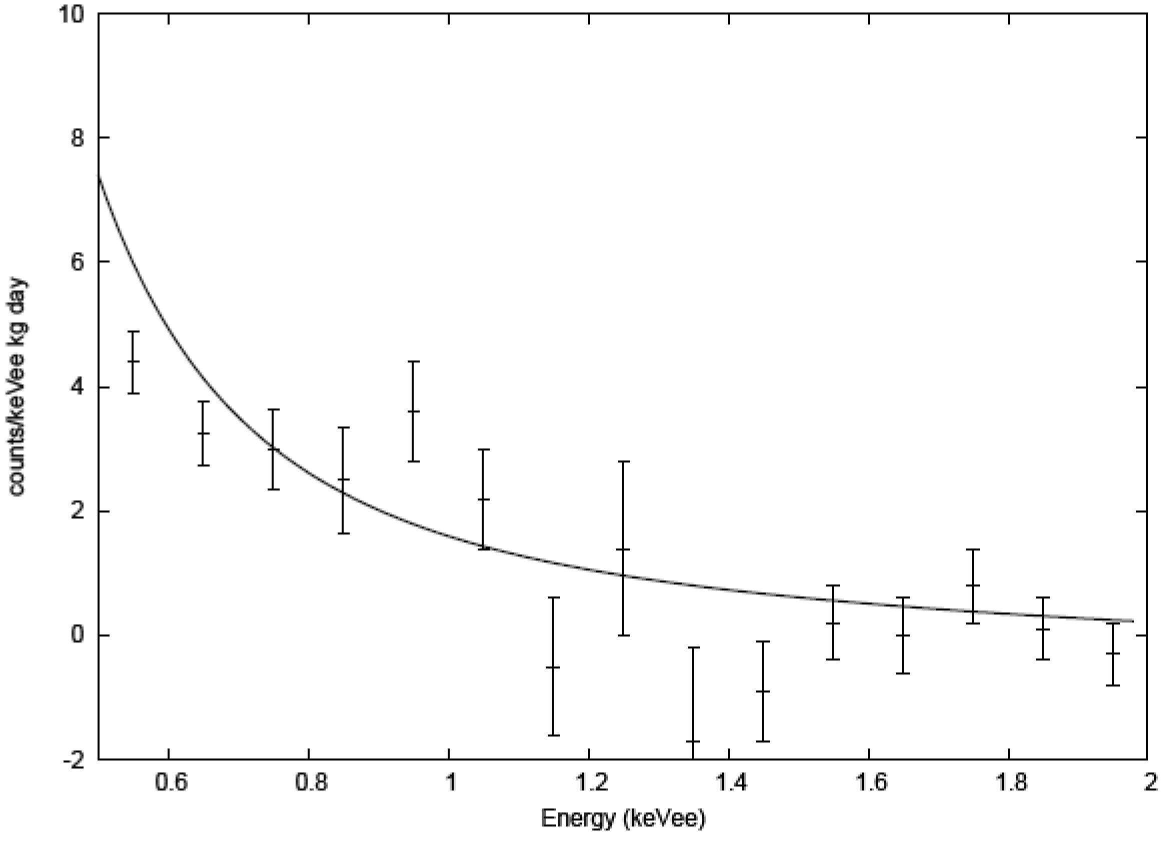
Mirror dark matter can fit the energy dependence of the CoGeNT spectrum

Shown is fit for an example:

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

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

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



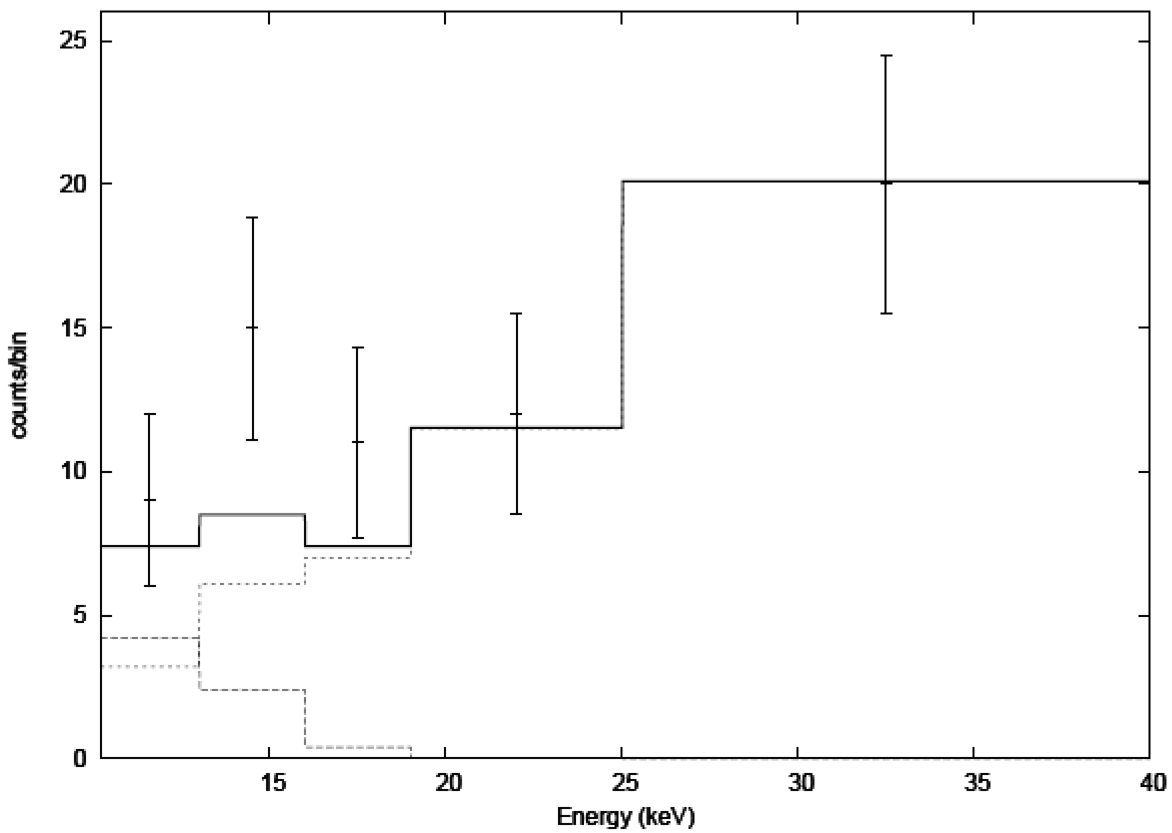
Mirror dark matter can fit the CRESST-II spectrum.

Shown is fit for an example:

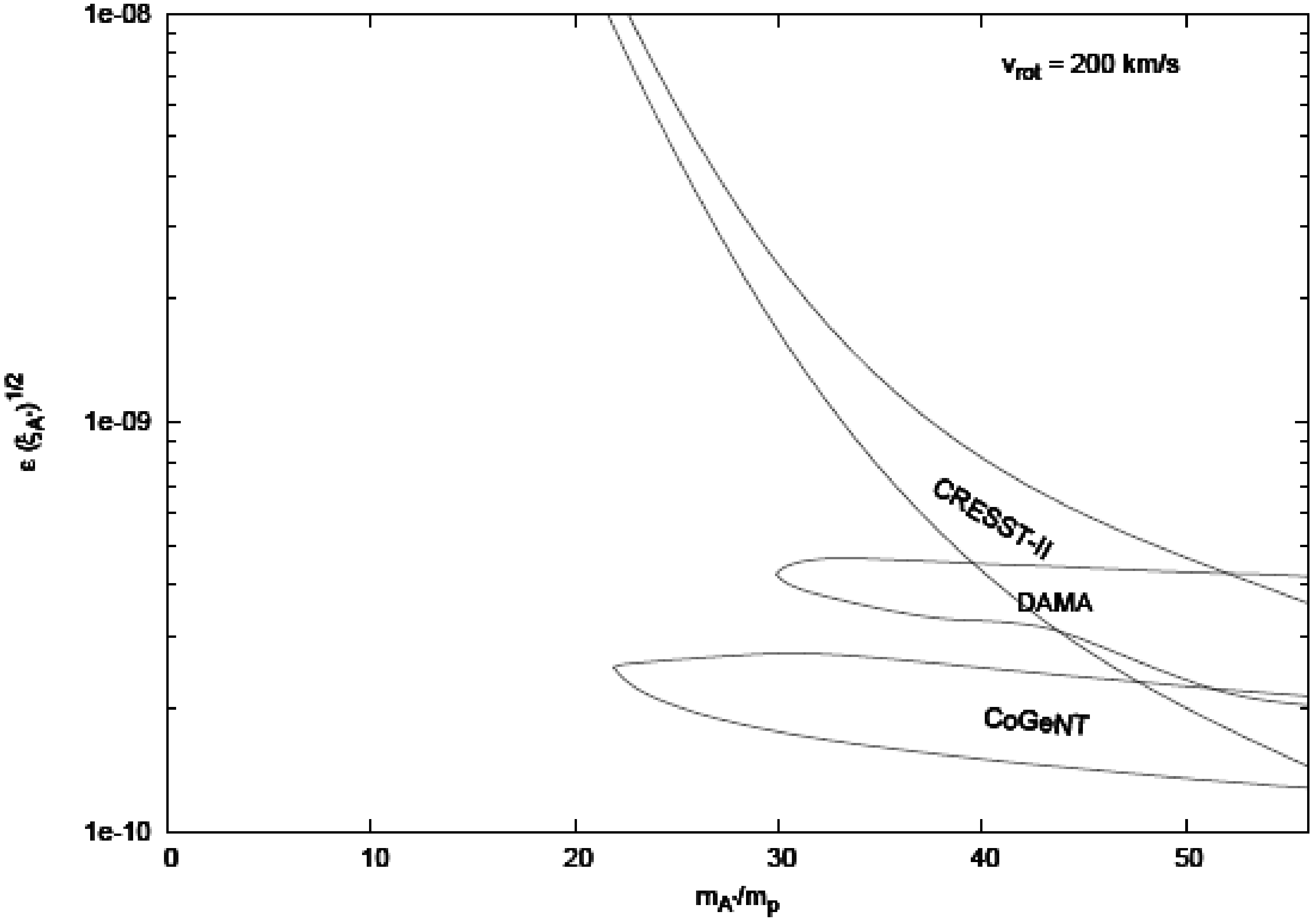
$$A' = \mathrm{Fe}'$$

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

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



Combined fit of DAMA, CoGeNT and CRESST-II



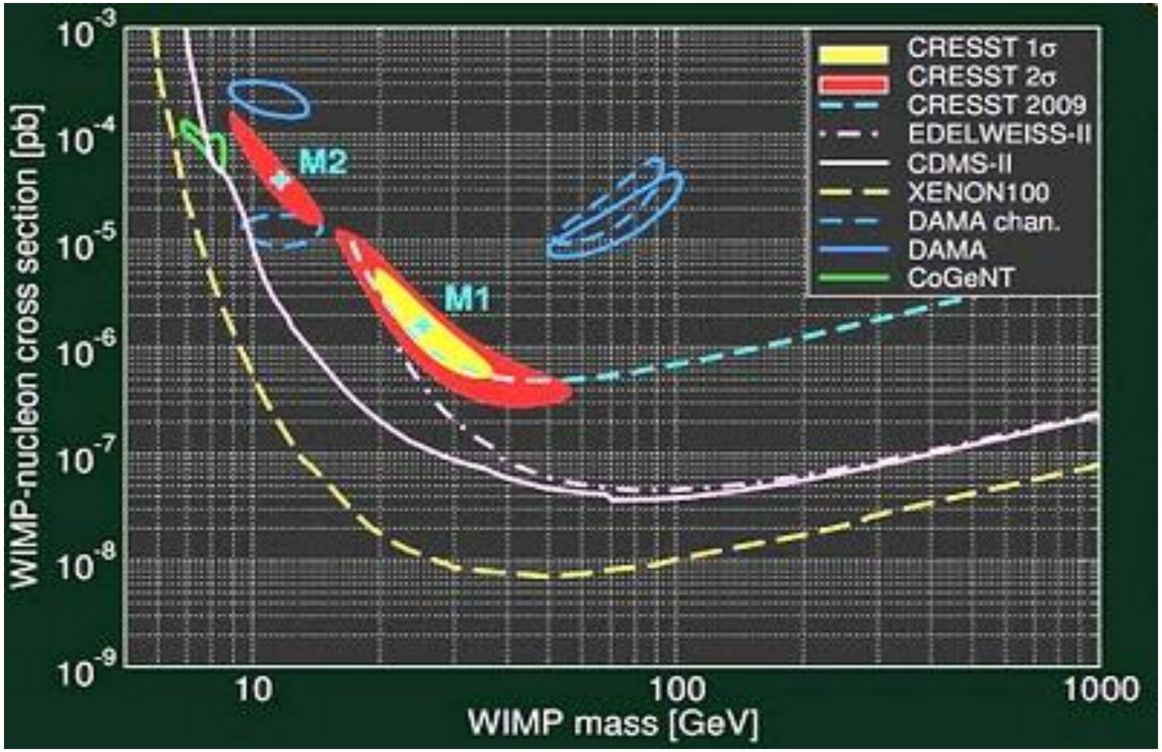
Mirror dark matter different to standard WIMP models

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

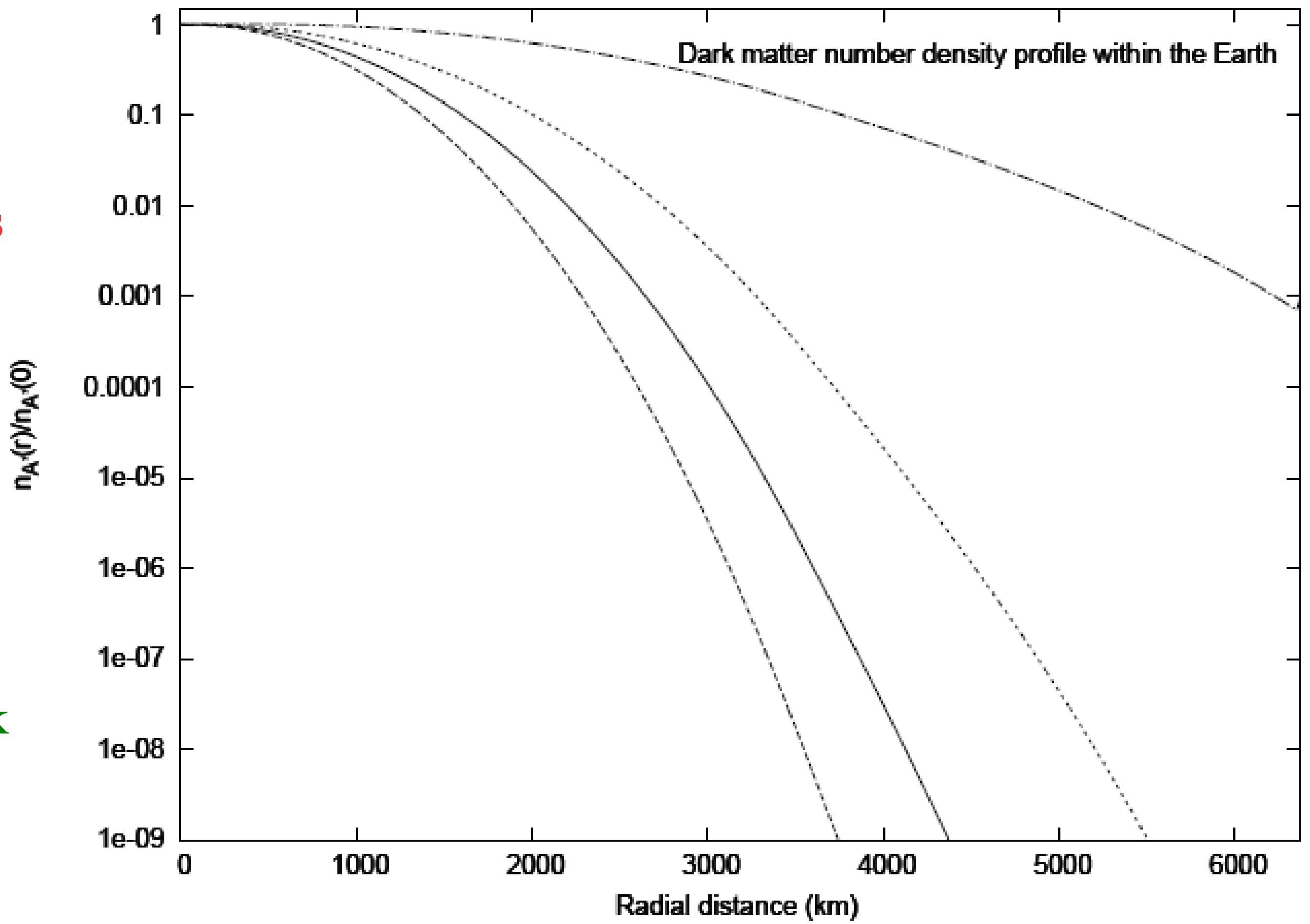


Diurnal signal

Mirror dark matter, and other self interacting dark matter candidates, can accumulate in the Earth.

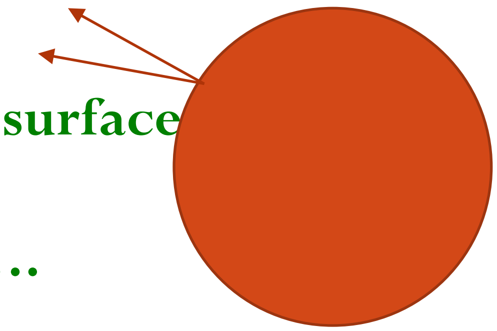
In this case, the halo wind can be blocked, and dark matter rates in experiments suppressed

The level of suppression depends on the direction of dark matter flux.



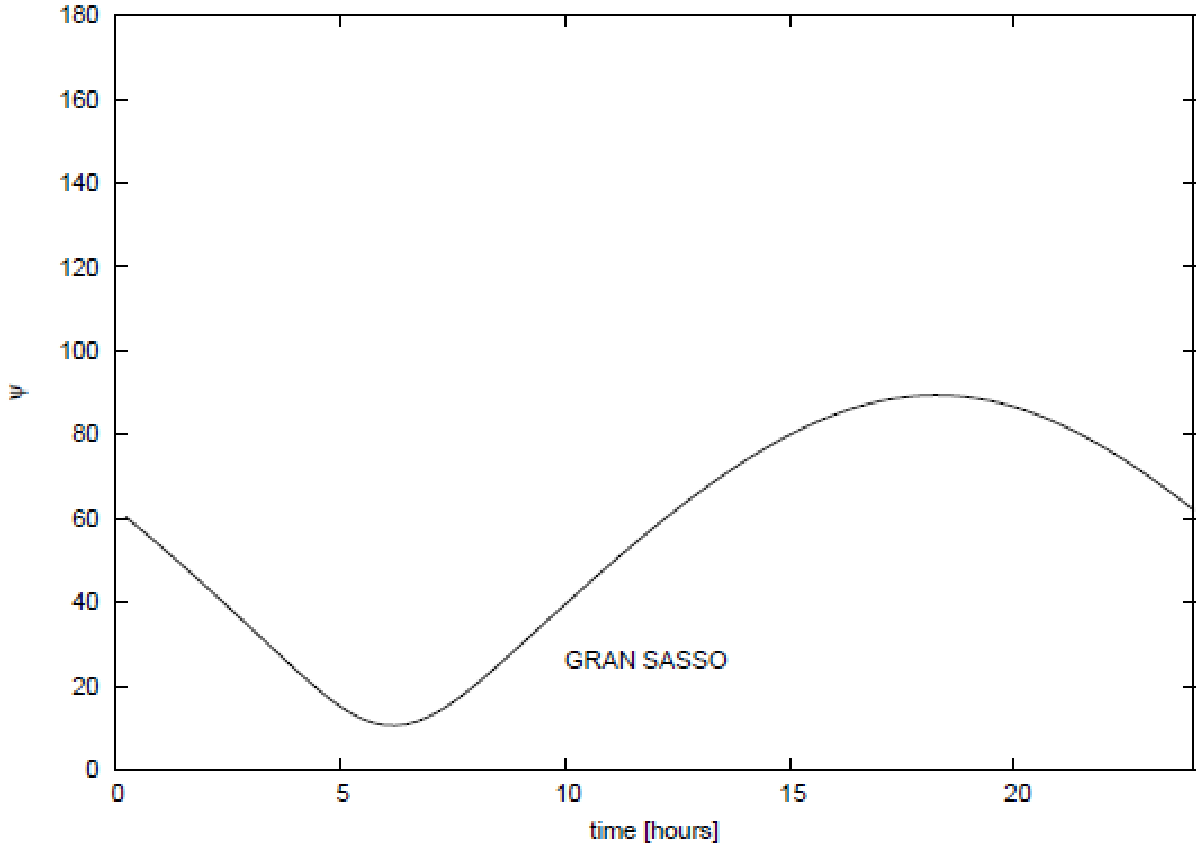
Diurnal signal

The angle between Earth's motion through the halo and normal to Earth's surface



This angle changes as the earth rotates….

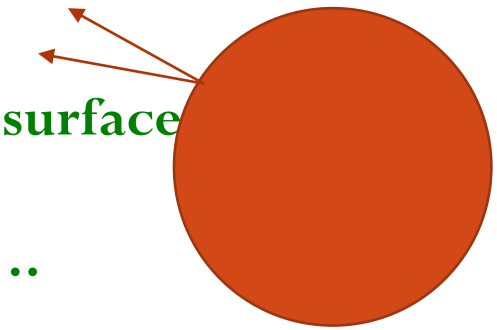
Dark matter wind through Earth's core



Dark matter wind directly above

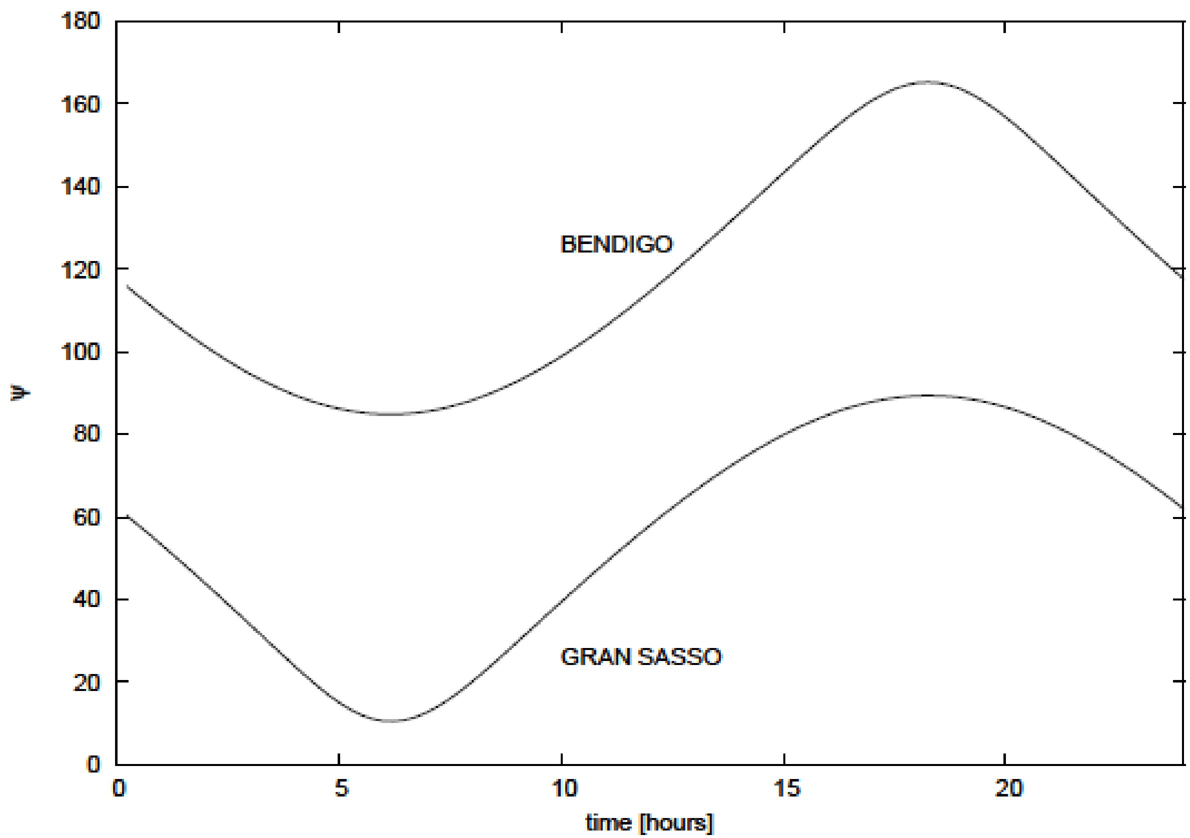
Diurnal signal

The angle between Earth's motion through the halo and normal to Earth's surface



This angle changes as the earth rotates….

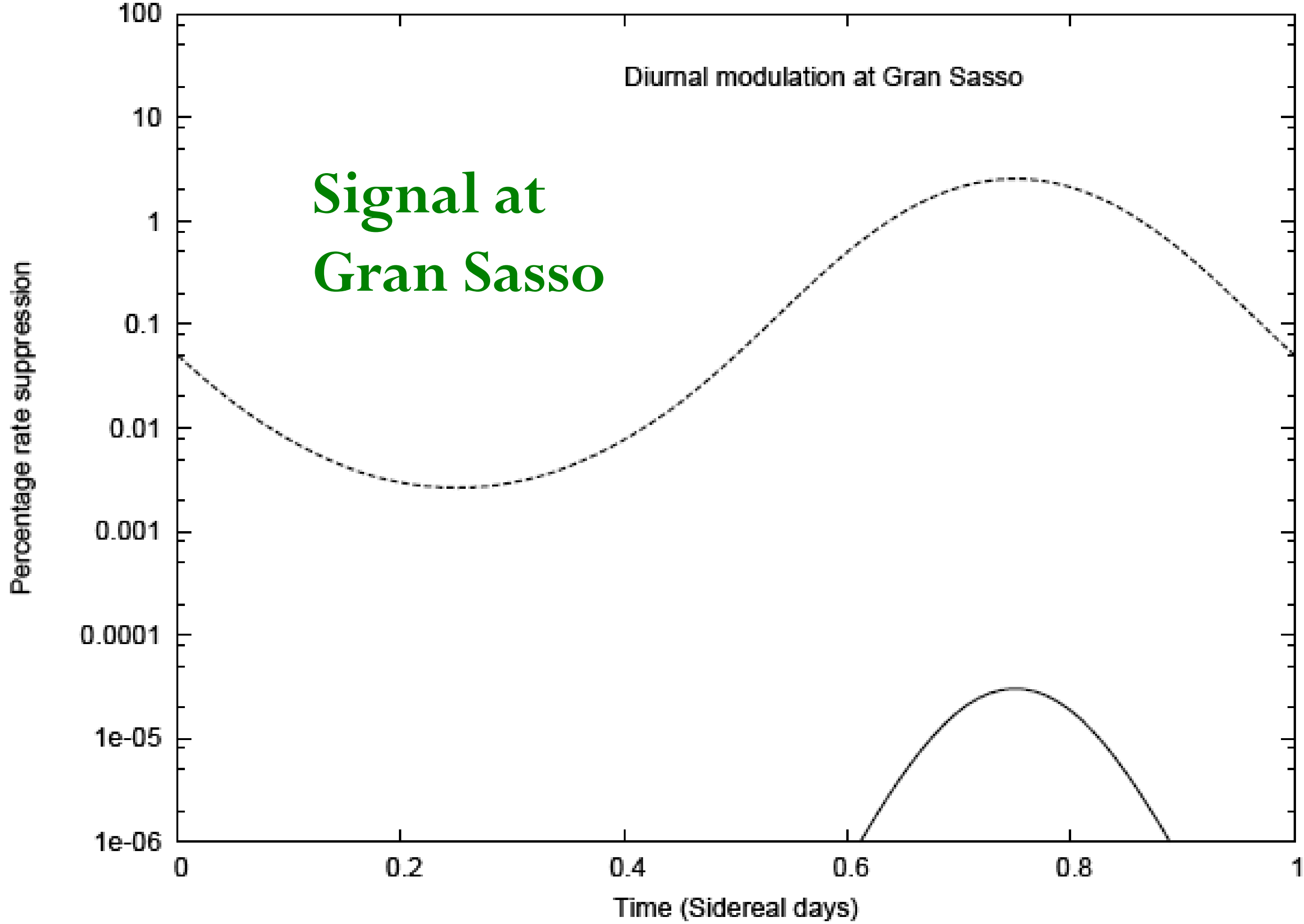
Dark matter wind through Earth's core



Dark matter wind directly above

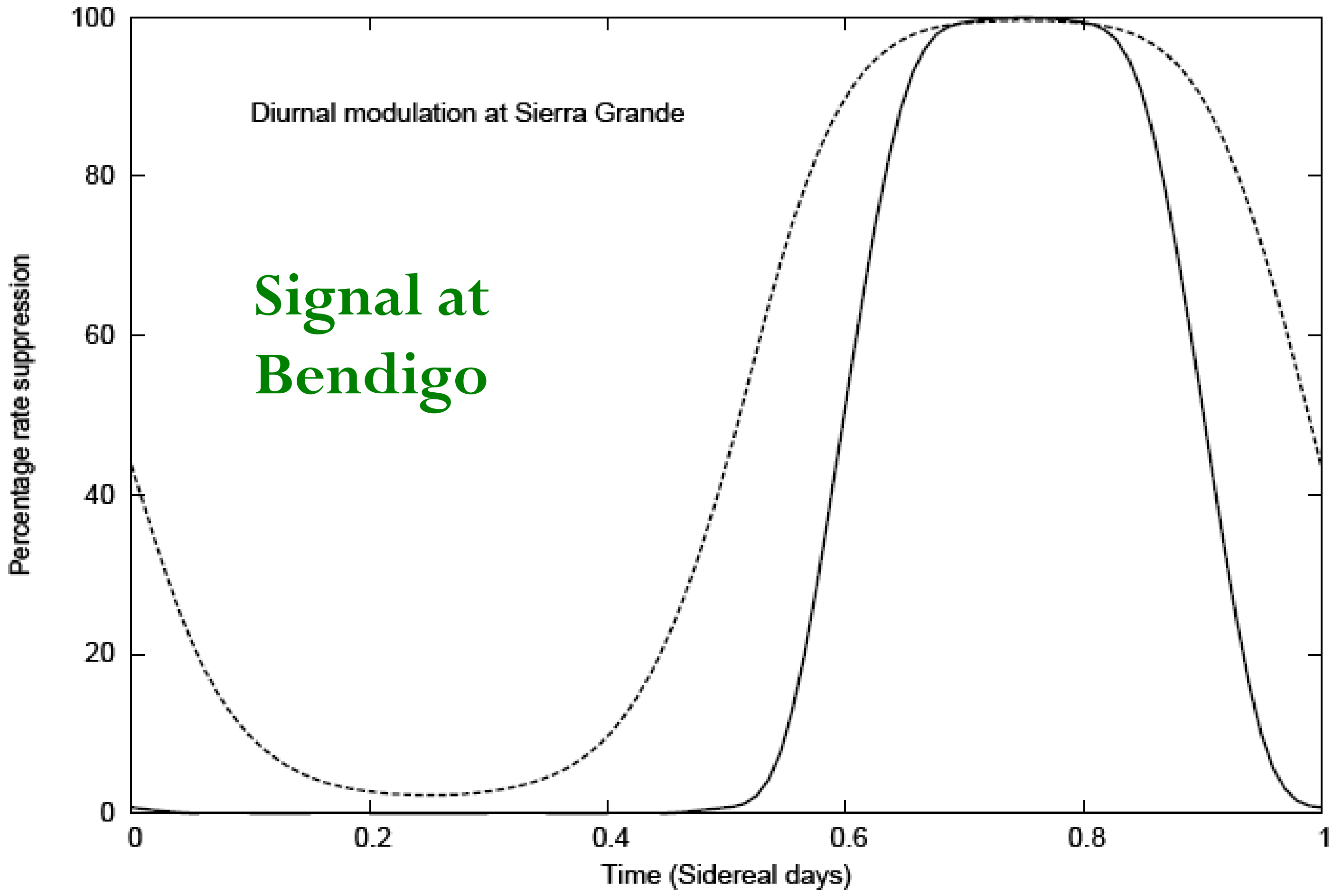
Diurnal signal

For northern hemisphere, diurnal variation is typically very small…



Diurnal signal

For Southern hemisphere, diurnal variation is typically very big…



Conclusions

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

The DAMA experiment may have actually detected galactic dark matter! Some support from CoGeNT and CRESST-II.

An experiment in the southern hemisphere is needed to

a) check the DAMA annual modulation is not related to seasons or detector location.

b) Search for Diurnal variation – completely unexplored territory...