Phenomenology of low mass WIMPs

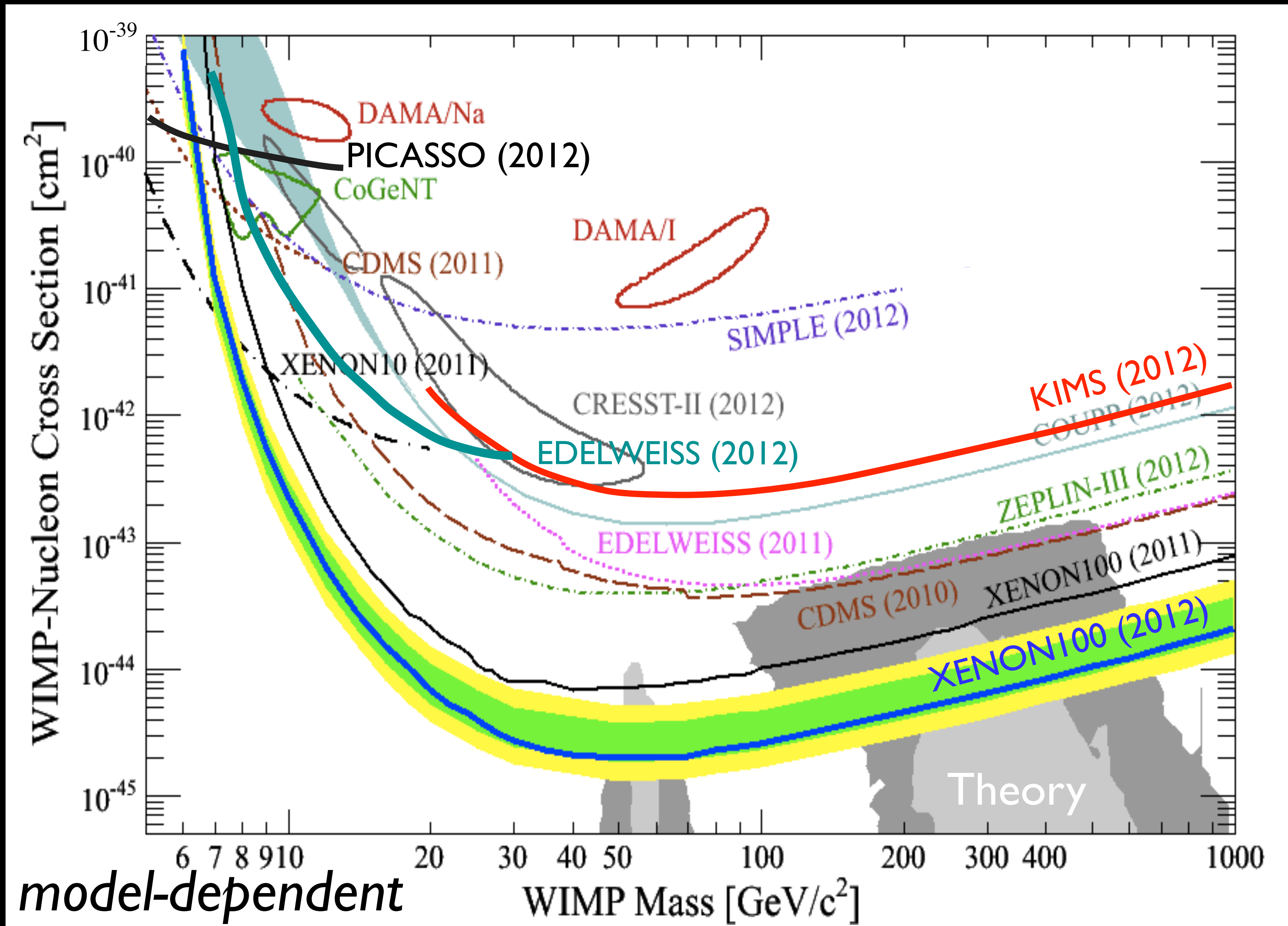
Light dark matter

Weakly-interacting

2-10 GeV/c^2 mass

Paolo Gondolo
University of Utah

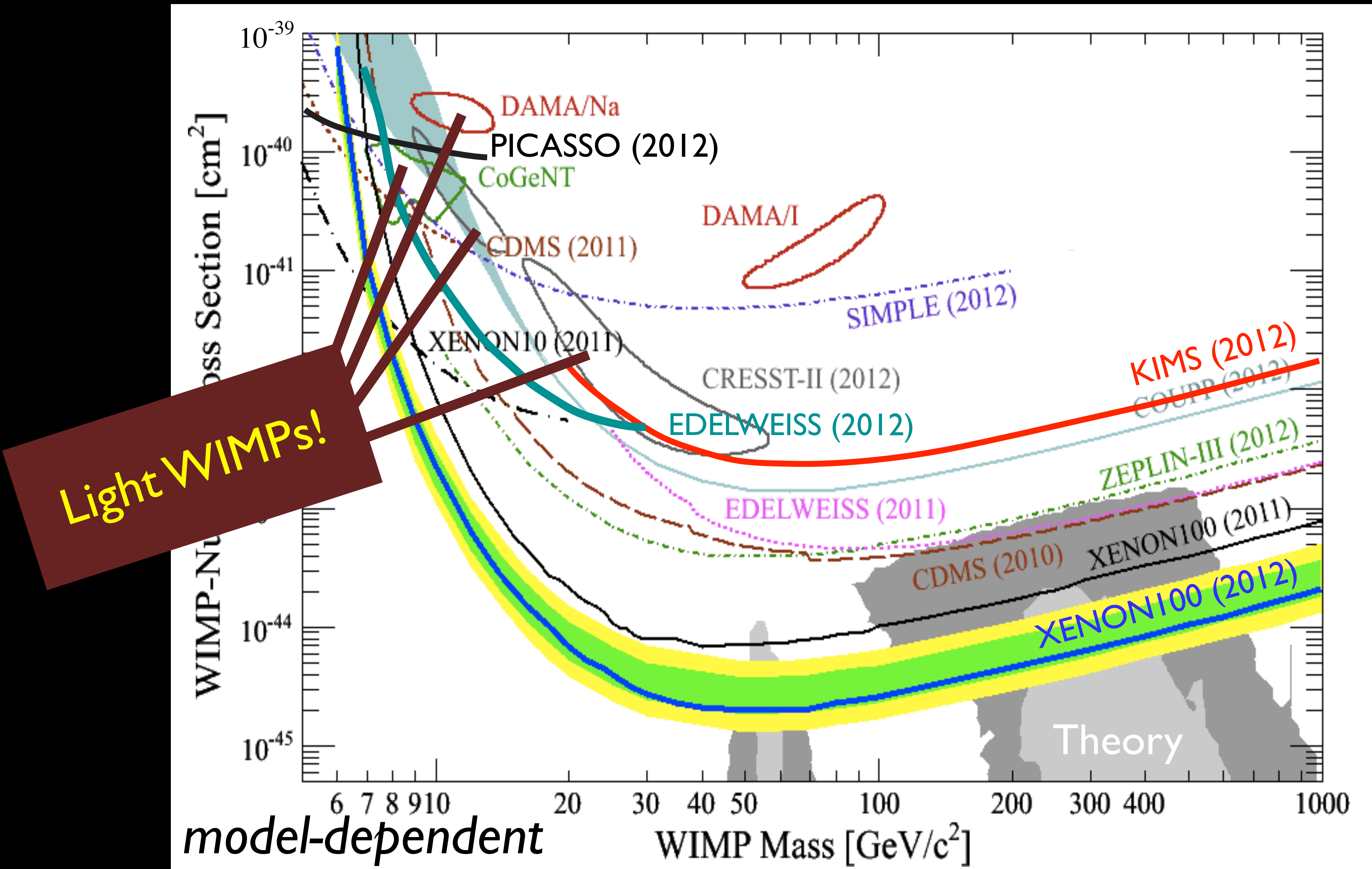
Spin-independent (July 2012)



From Aprile et al 2012 (modified)

1pb = 10^{-36} cm^2

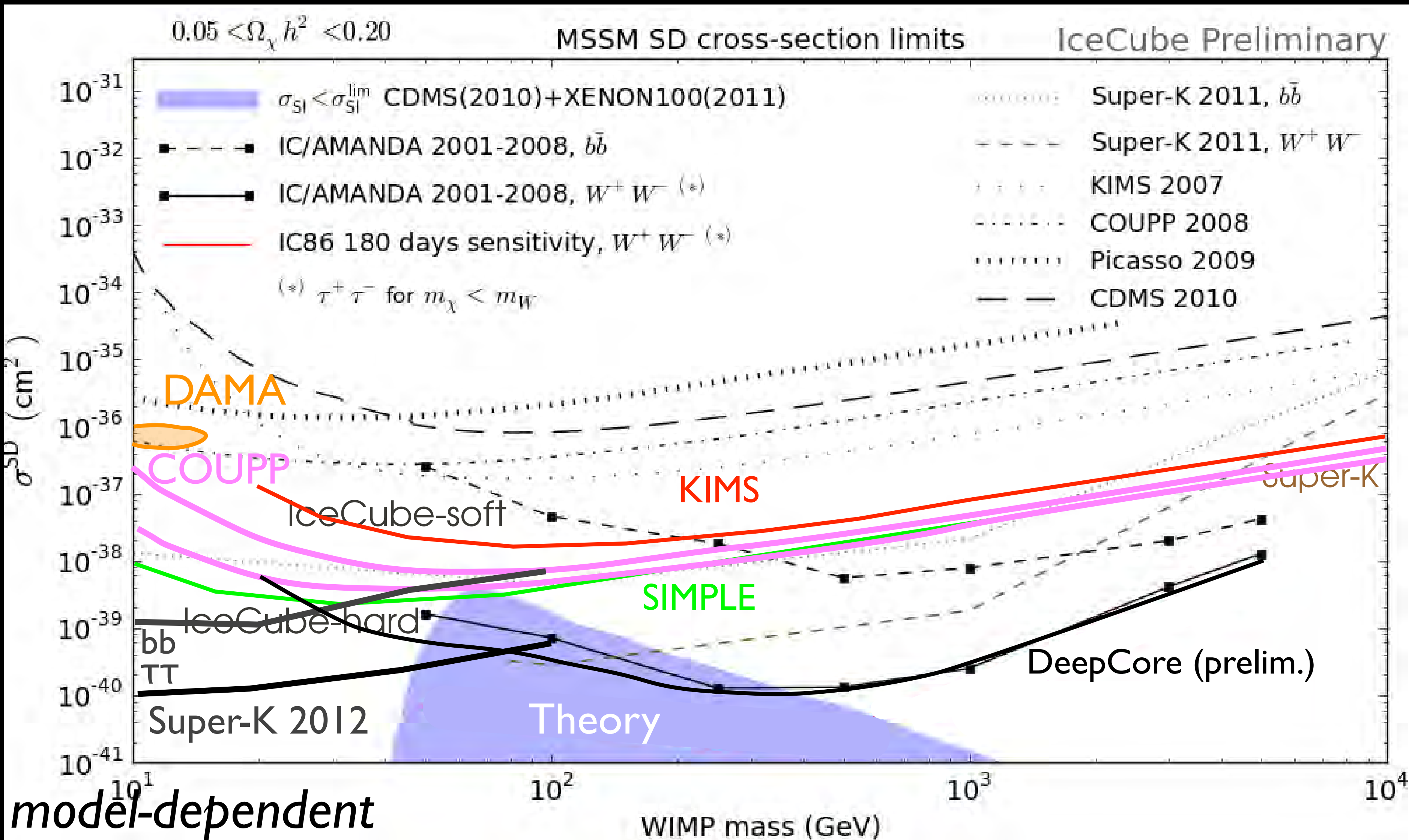
Spin-independent (July 2012)



From Aprile et al 2012 (modified)

1pb = 10^{-36} cm^2

Spin-dependent (July 2012)

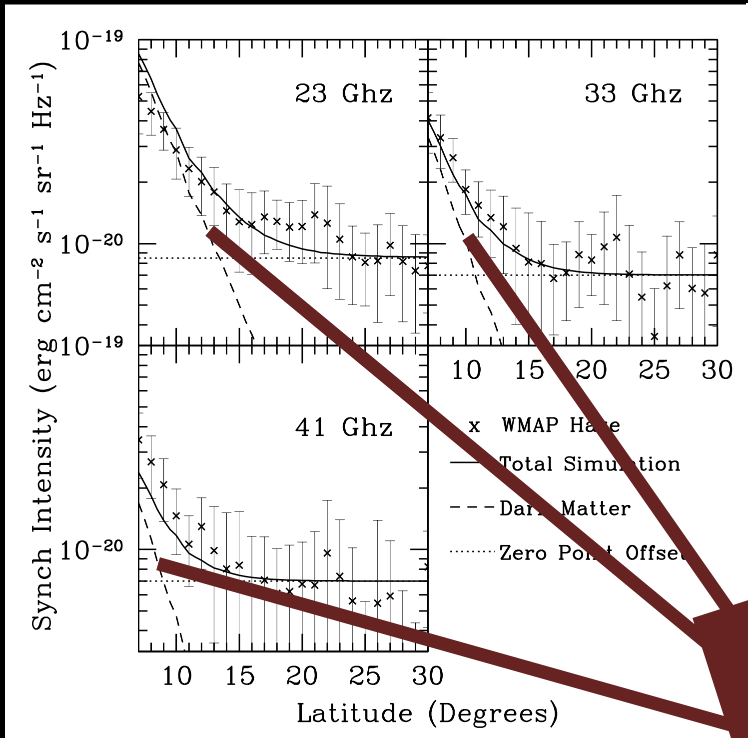


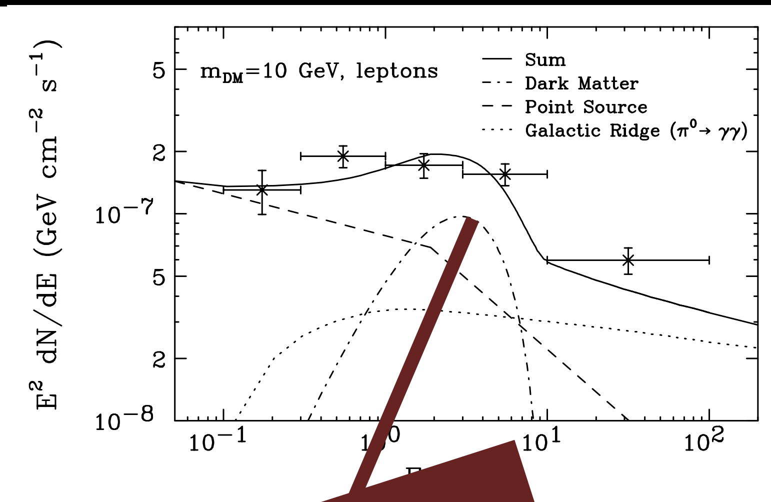
model-dependent

Adapted from Danninger at TAUP 2011, Rott at Neutrino 2012

1pb = 10^{-36} cm^2

Many see light WIMPs in outer space



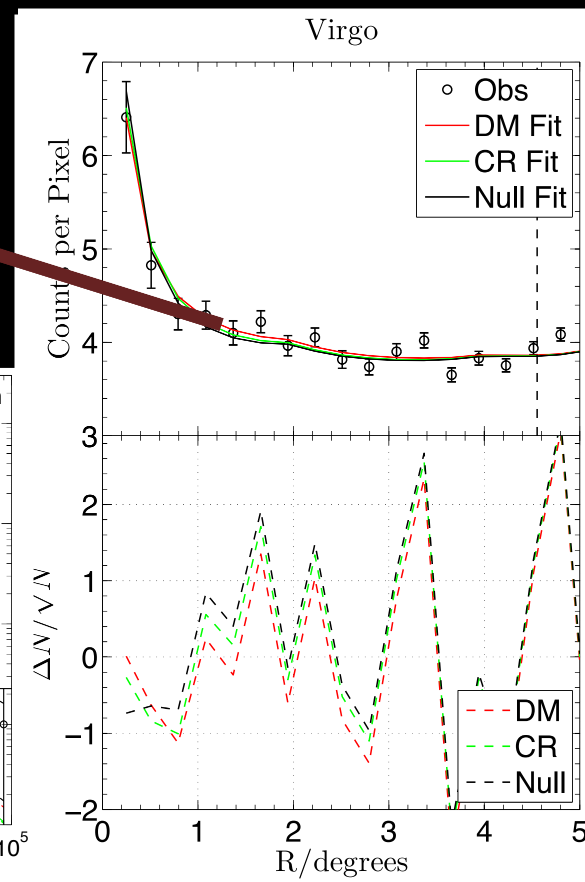


Light WIMPs!

Light WIMPs!

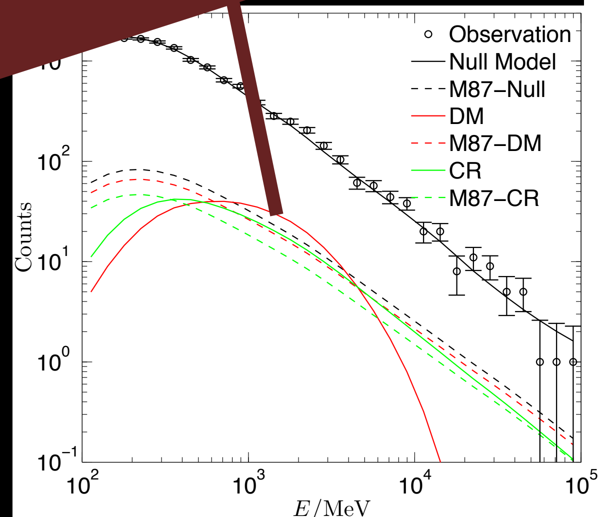
Han e al 2012

Diffuse
γ-ray excess
near centers of
galaxy clusters



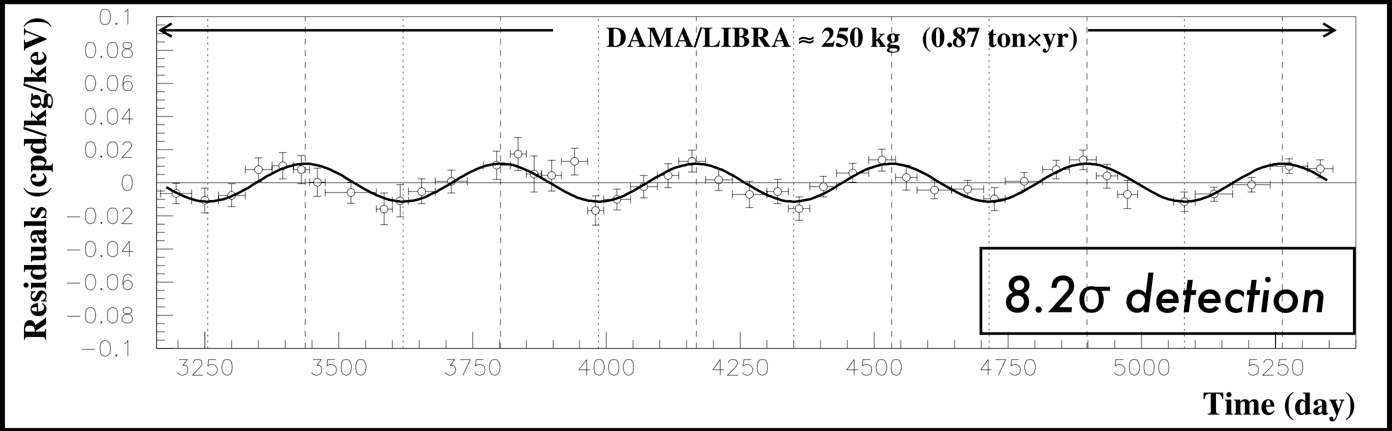
Diffuse γ-ray and microwave excess near the Galactic Center

Finkbeiner 2004
Hooper et al 2007
Hooper, Goodenough 2010
Hooper, Linden 2010-11

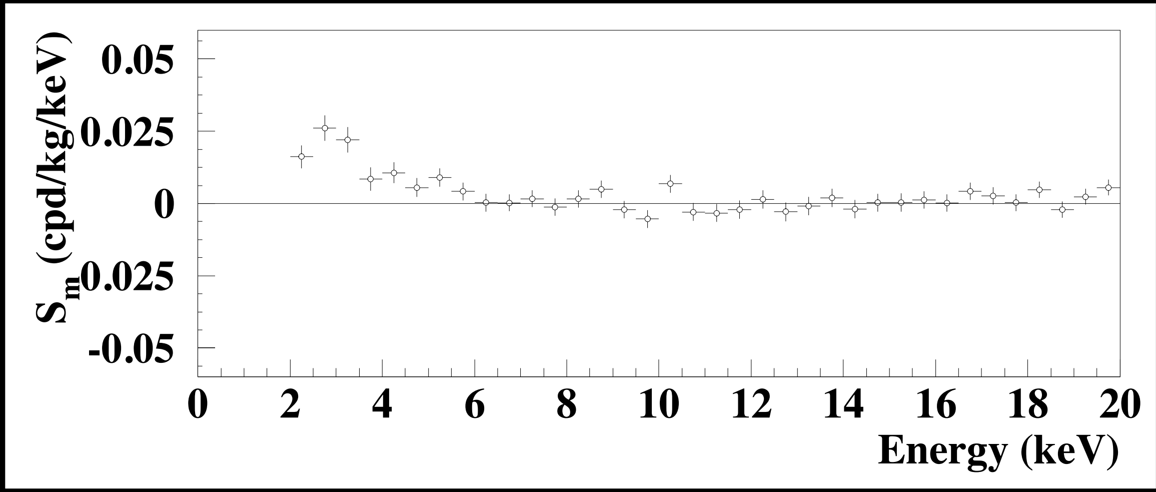


Friday, July 27, 12

The DAMA annual modulation

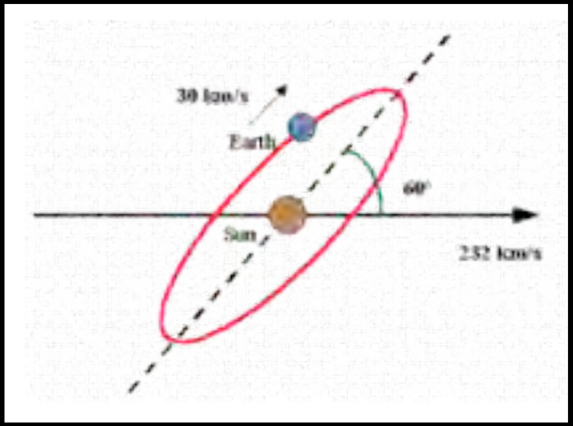


Bernabei et al 1997-10

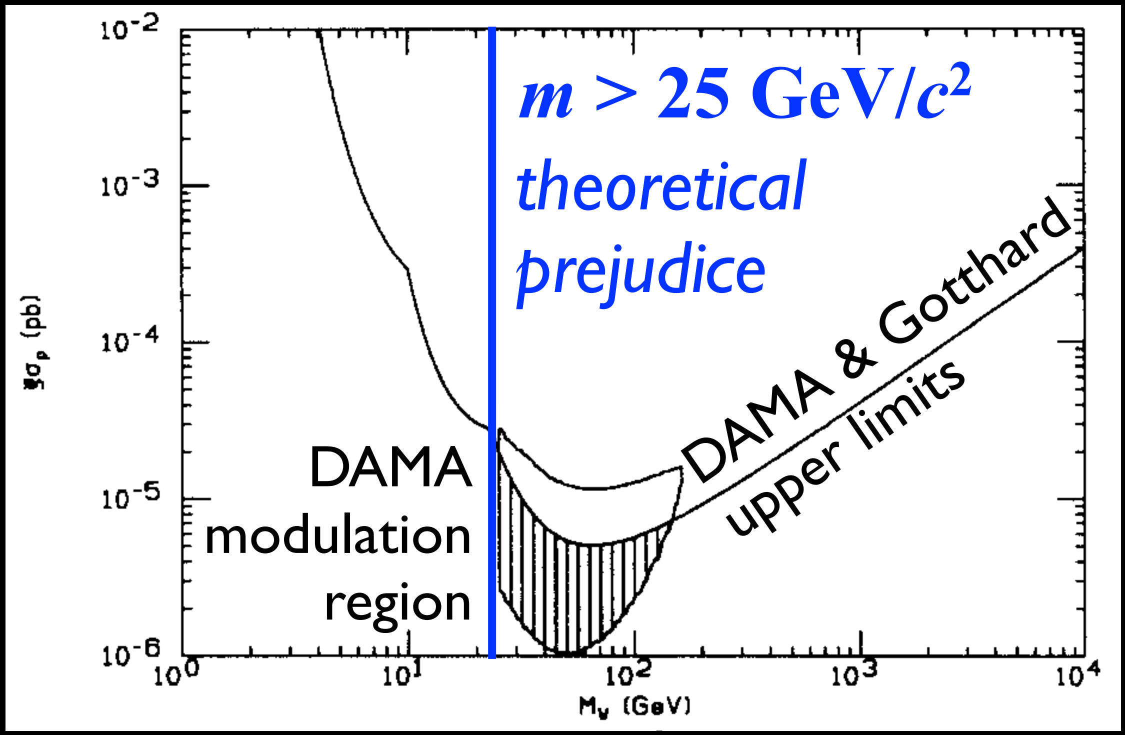


$$S = S_0 + S_m \cos[\omega(t - t_0)]$$

Drukier, Freese, Spergel 1986



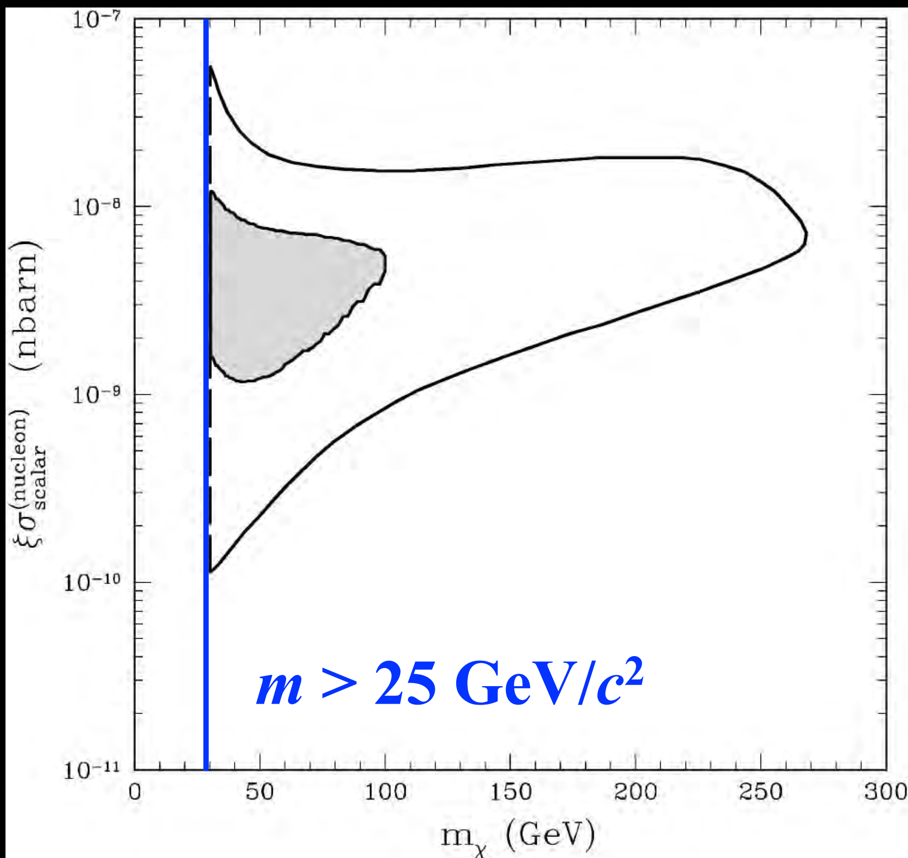
WIMP interpretation of the DAMA modulation



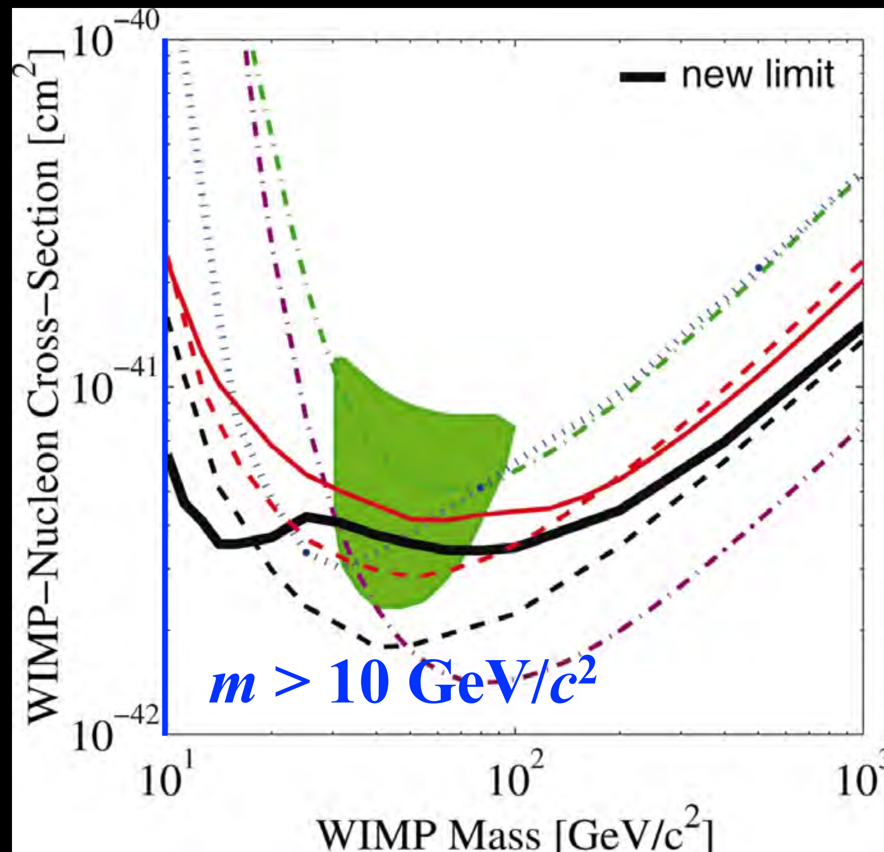
Bernabei et al, TAUP 1997

WIMP interpretation of the DAMA modulation

The theoretical prejudice continued into 2003..........



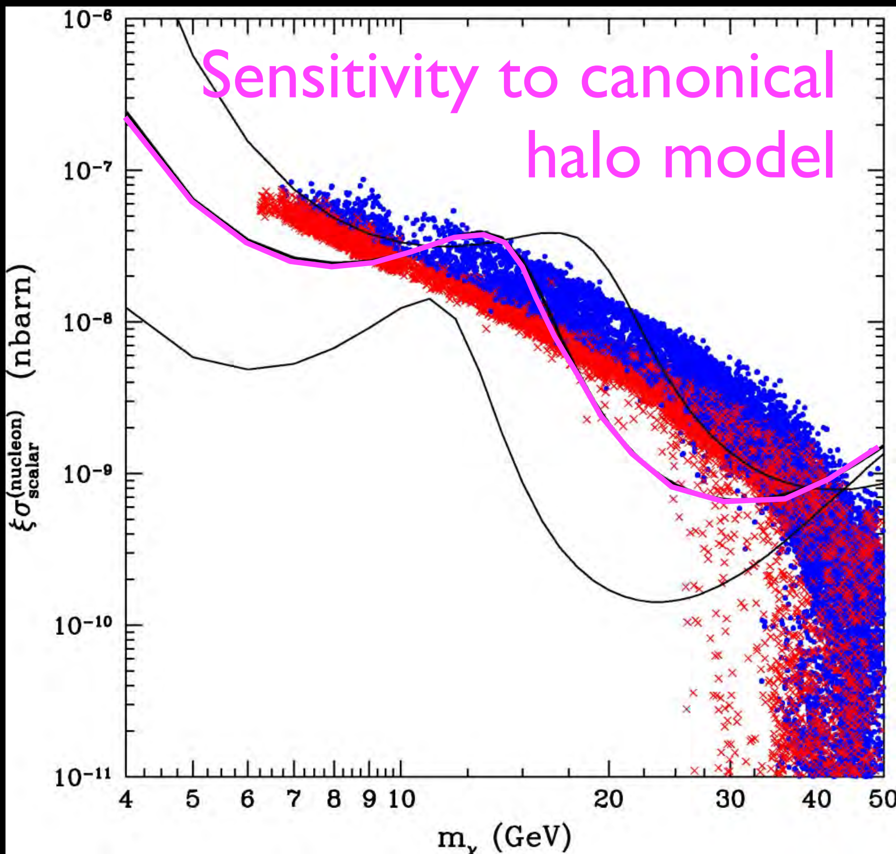
Belli, Cerulli, Fornengo, Scopel 2002



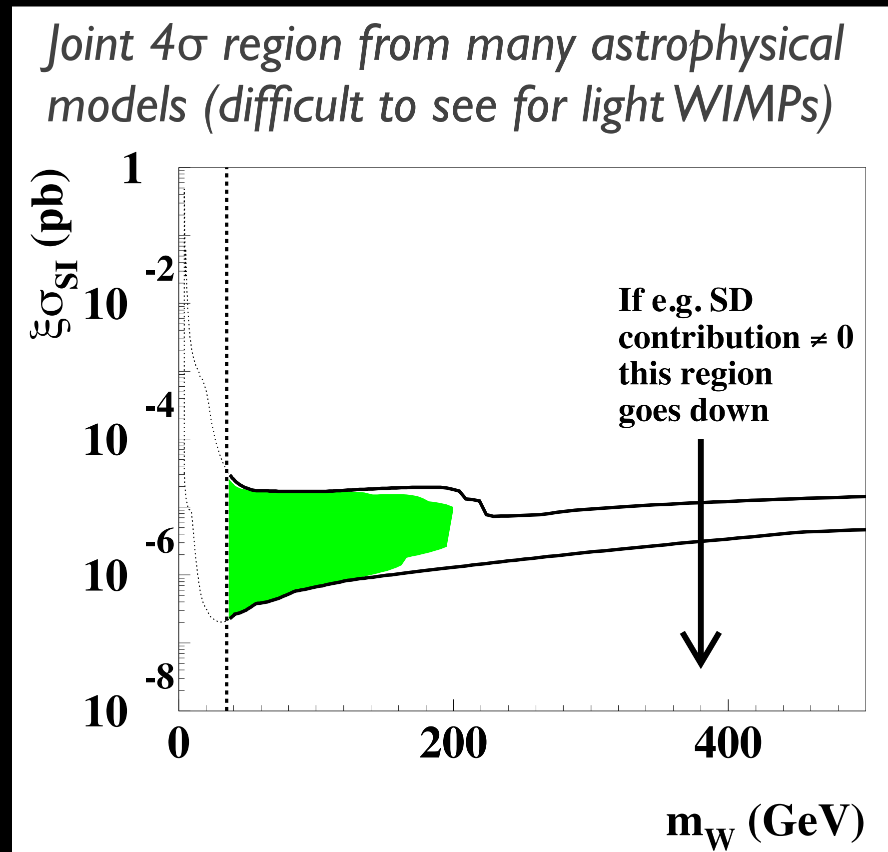
Benoit et al 2002;Akerib et al 2003

WIMP interpretation of the DAMA modulation

The theoretical prejudice continued into 2003..........



Bottino, Donato, Fornengo, Scopel hep-ph/0304080



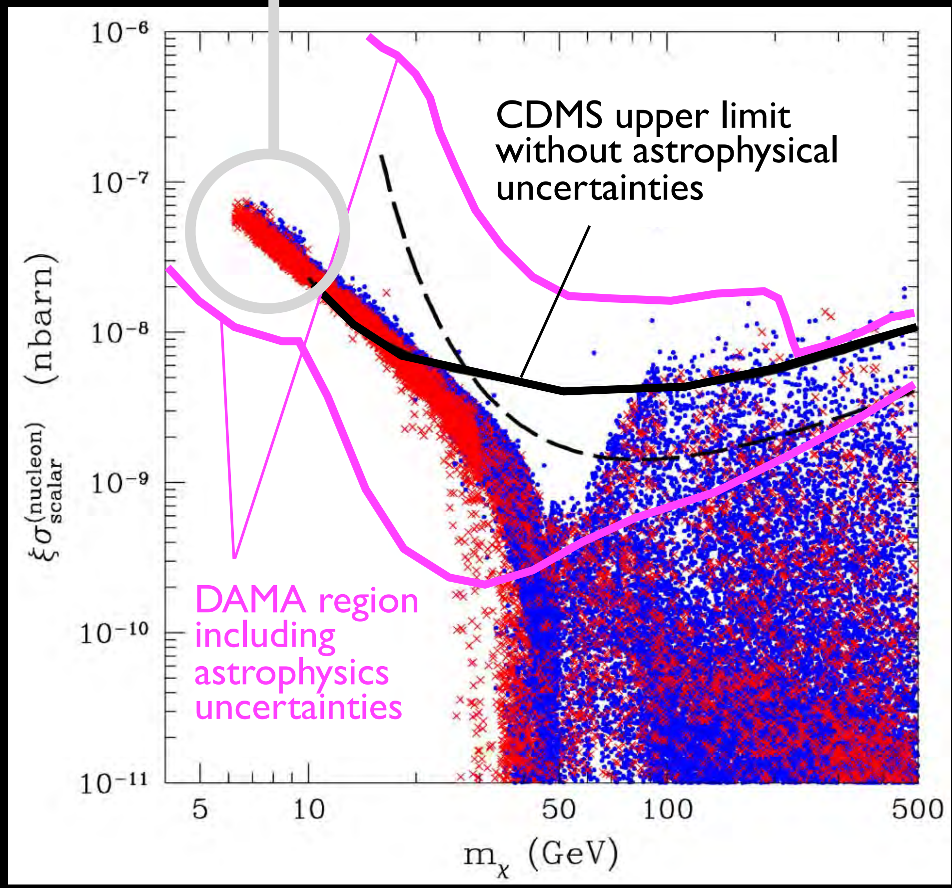
Bernabei et al, astro-ph/0307403

WIMP interpretation of the DAMA modulation

The theoretical prejudice continued into 2003..........

...........when 7-10 GeV neutralinos were resurrected

No limits for light WIMPs



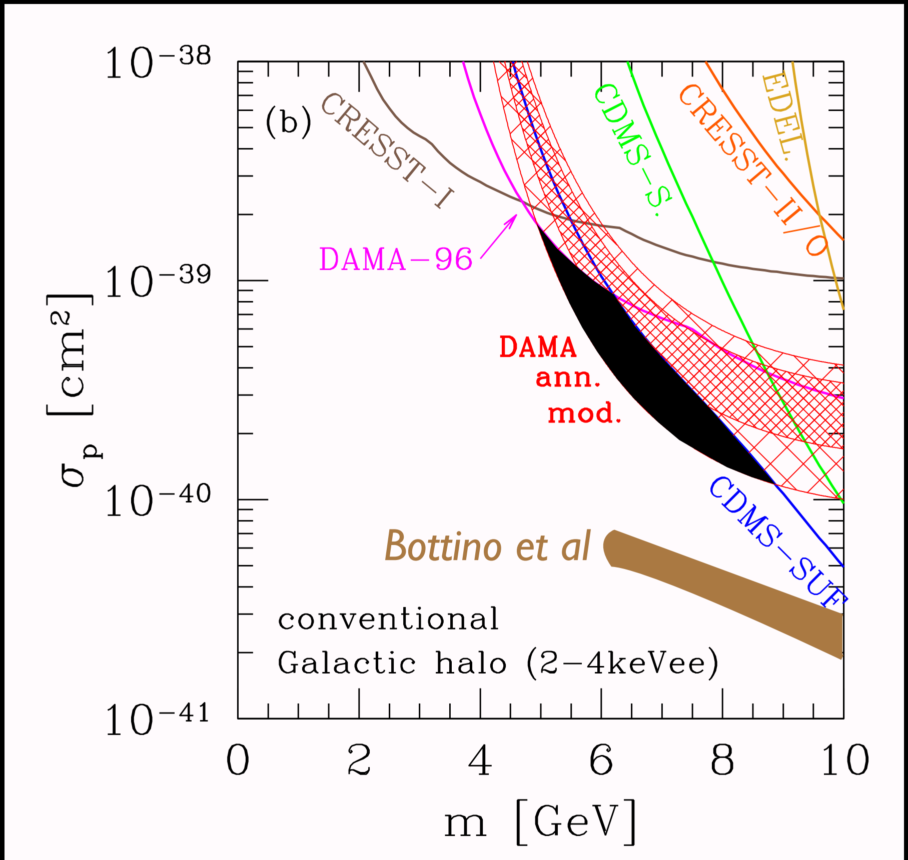
Bottino, Donato, Fornengo, Scopel 2003

WIMP interpretation of the DAMA modulation

The theoretical prejudice continued into 2003..........

...........when 7-10 GeV neutralinos were resurrected

..........and for the first time experiments were compared for light WIMPs



Gondolo, Gelmini 2004

"Los muertos que vos matáis gozan de buena salud." (Gelmini, TAUP 1995)

Light WIMPs in the Maxwellian halo model are possible!

Many papers after ours: *Petriello, Zurek 2008; Bottino et al 2008; Chang, Pierce, Weiner 2008; Fairbairn, Schwetz 2008; Hooper, Petriello, Zurek, Kamionkowski 2008; Chang, Kribs, Tucker-Smith, Weiner 2008; Savage, Gelmini, Gondolo, Freese 2008, 2010; .....*

The CoGeNT modulation

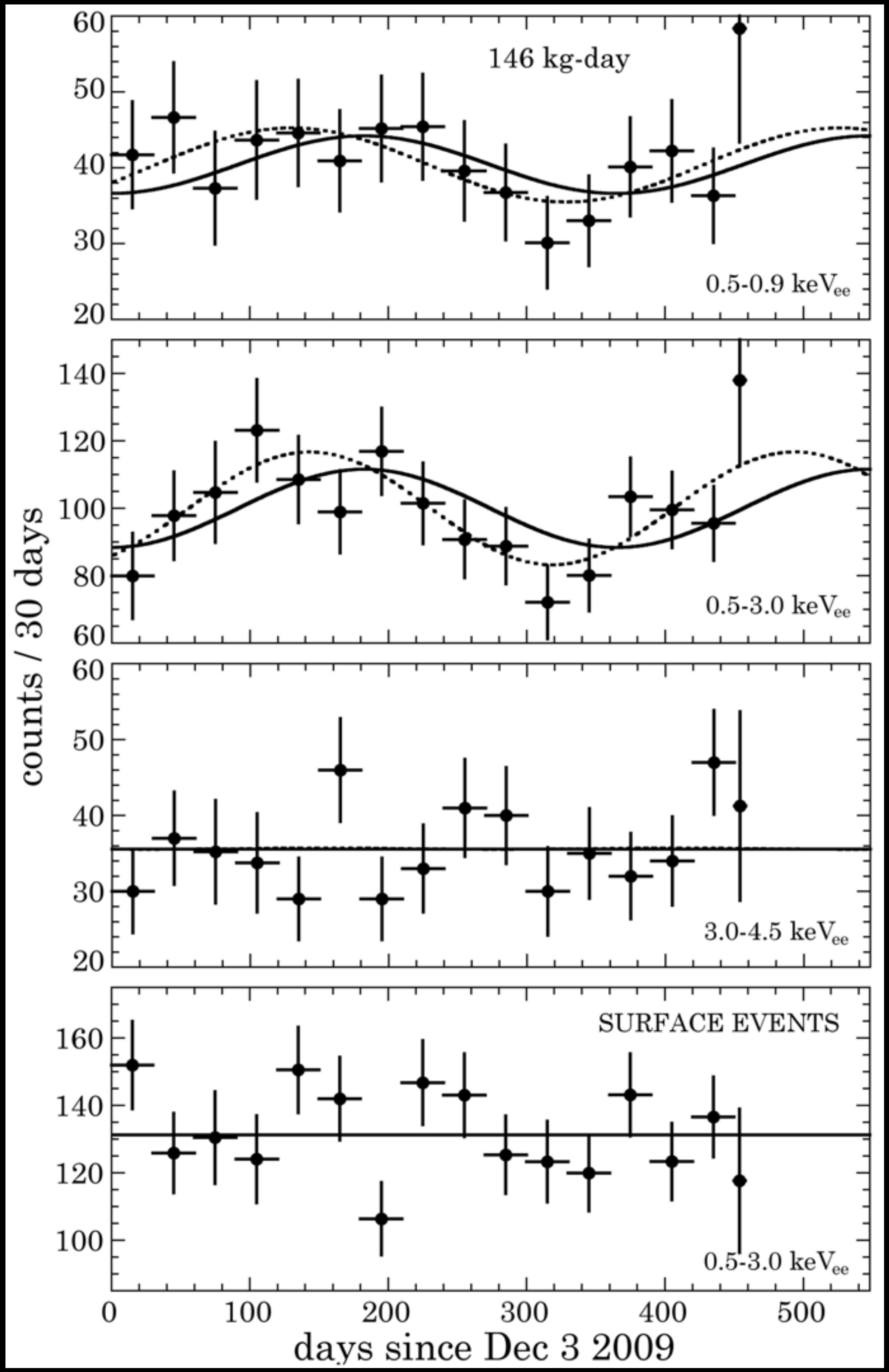
The CoGeNT "irreducible excess" (*) modulates with a period of one year and a phase compatible with DAMA's annual modulation.

Aalseth et al 1106.0650

(*) Partly due to extra surface events

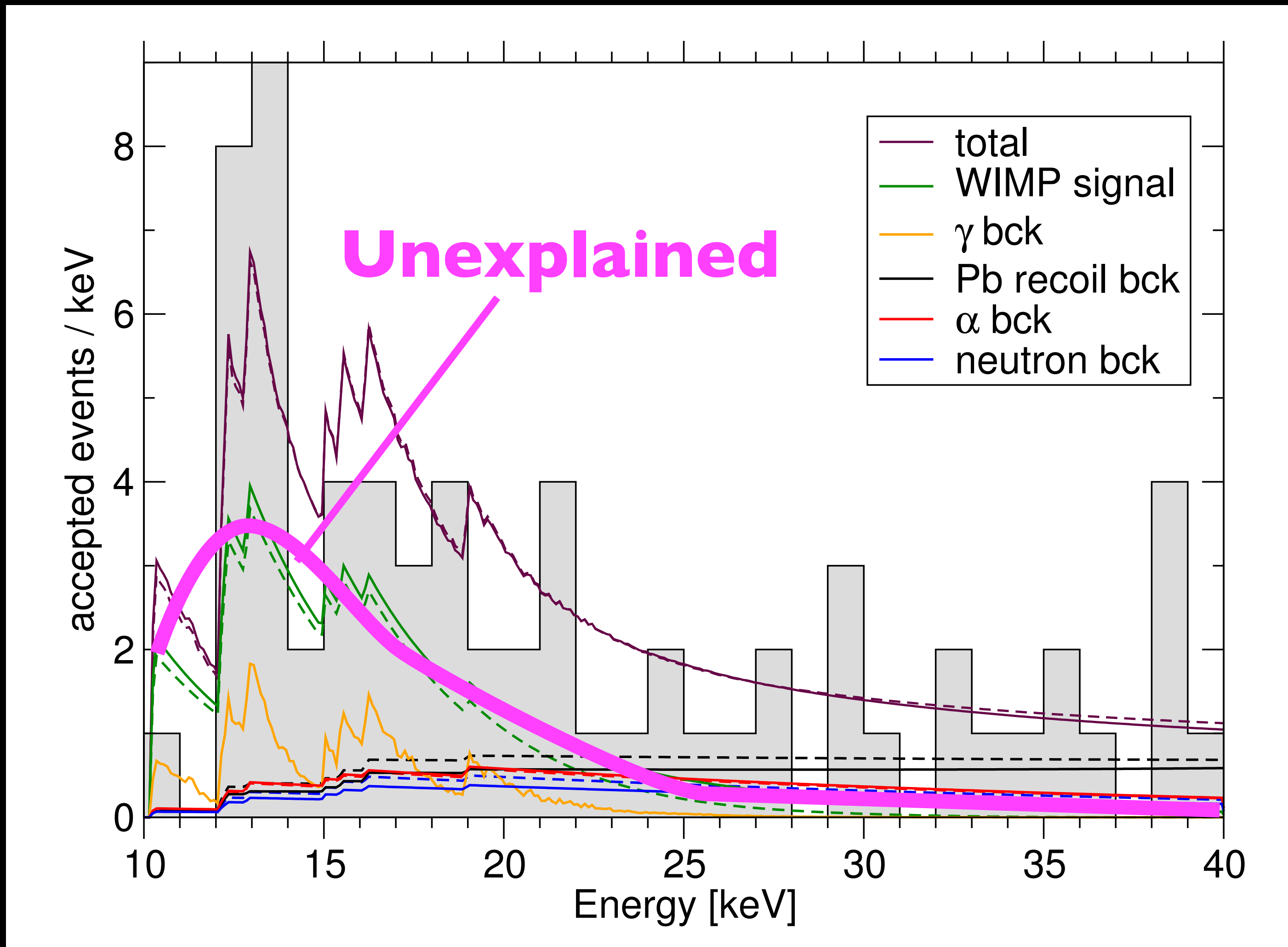
Caveat:
"Rates look flatter on second year."

Collar, this conference



The CRESST unexplained excess

67 observed events cannot all be explained by background at 4σ



Adapted from Anglehor et al 2011

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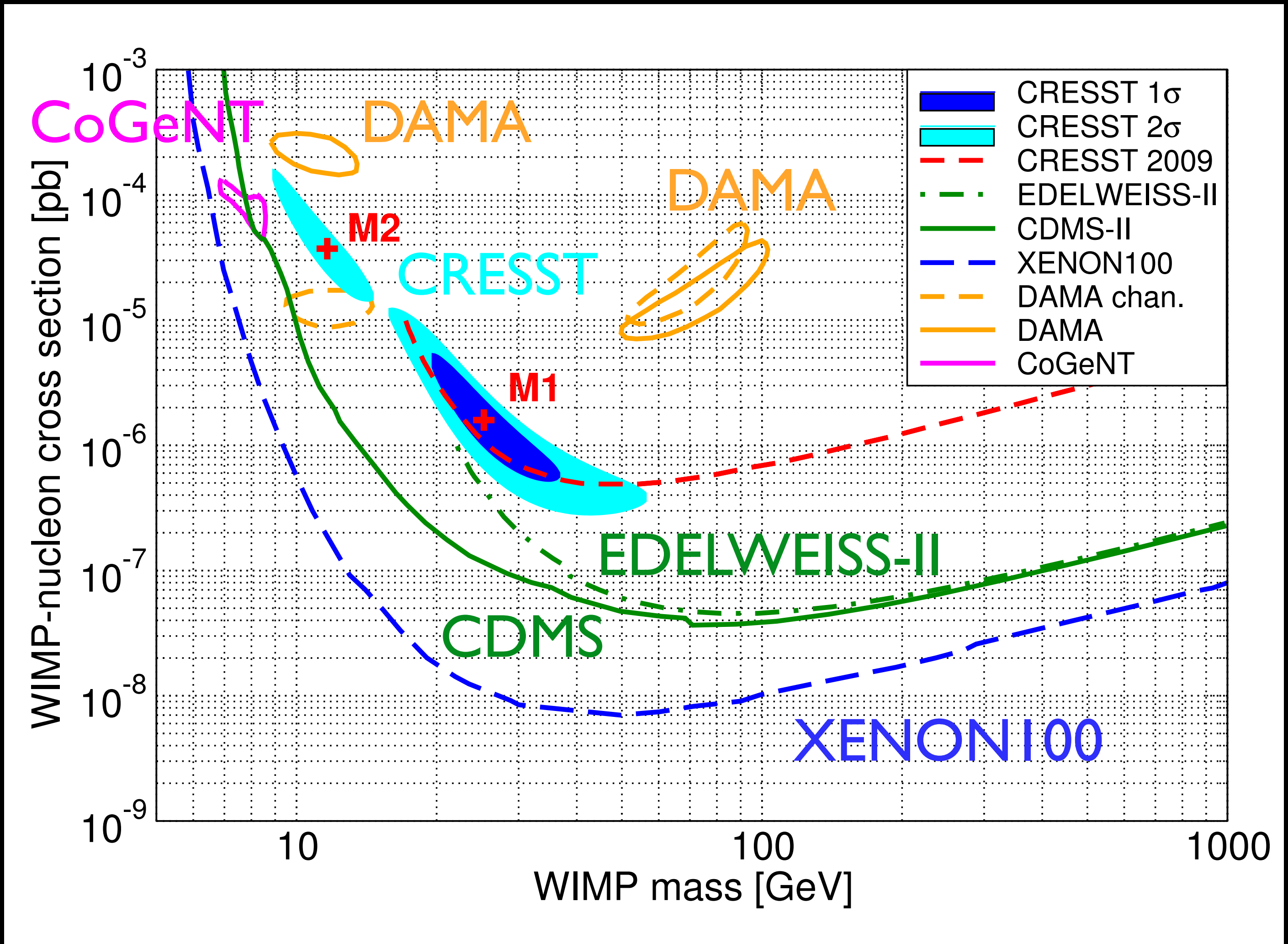
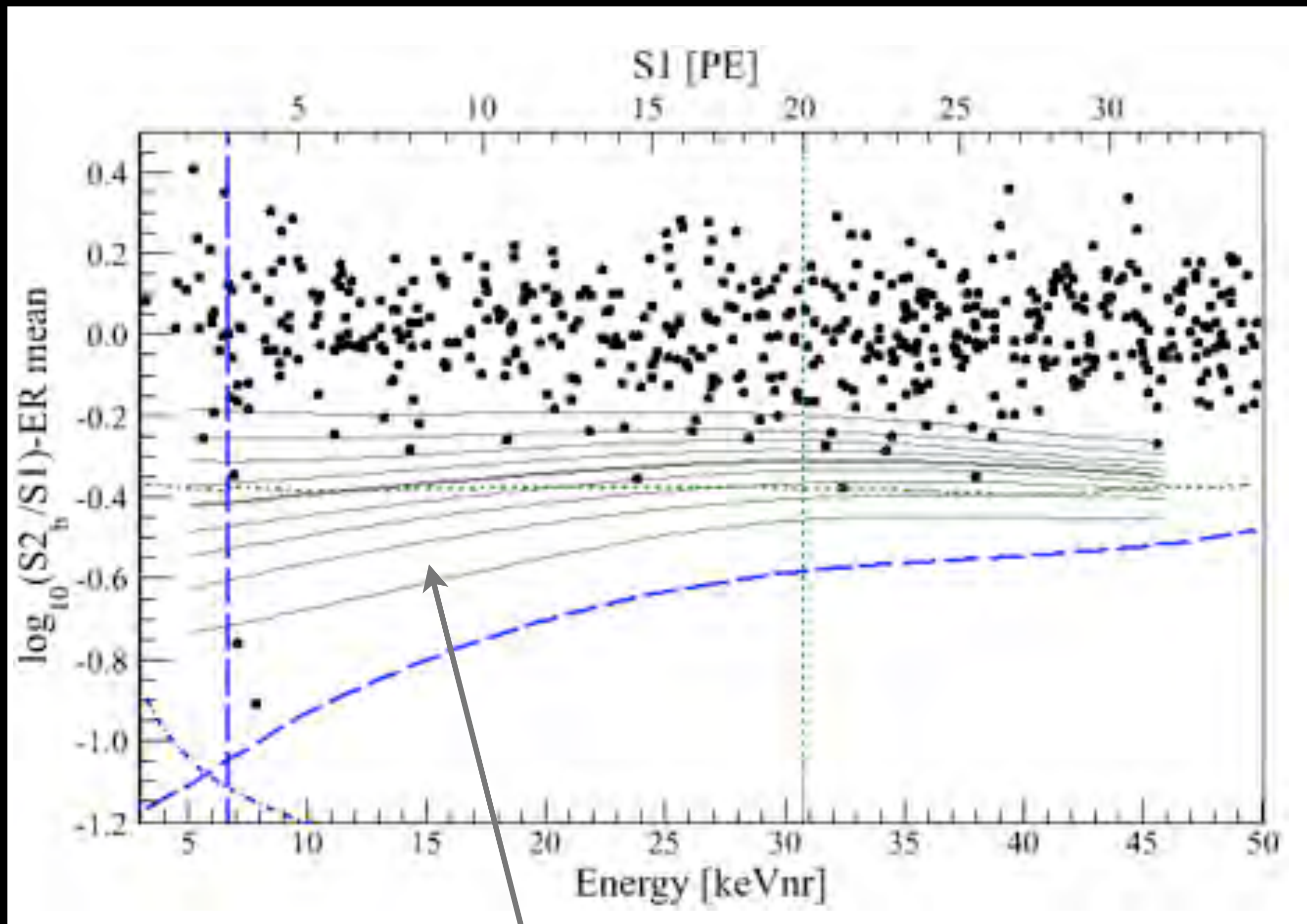


model-dependent

Adapted from Anglehor et al 2011

Limits from XENON-100, KIMS, CDMS, ...

Upper limit on WIMP-nucleon cross section
from XENON-100 (model dependent)



Aprile (for XENON-100 collab.), DarkAttack 2012

2 events observed

0.79±0.16 γ plus $0.17^{+0.12}_{-0.7}$ neutrons expected background

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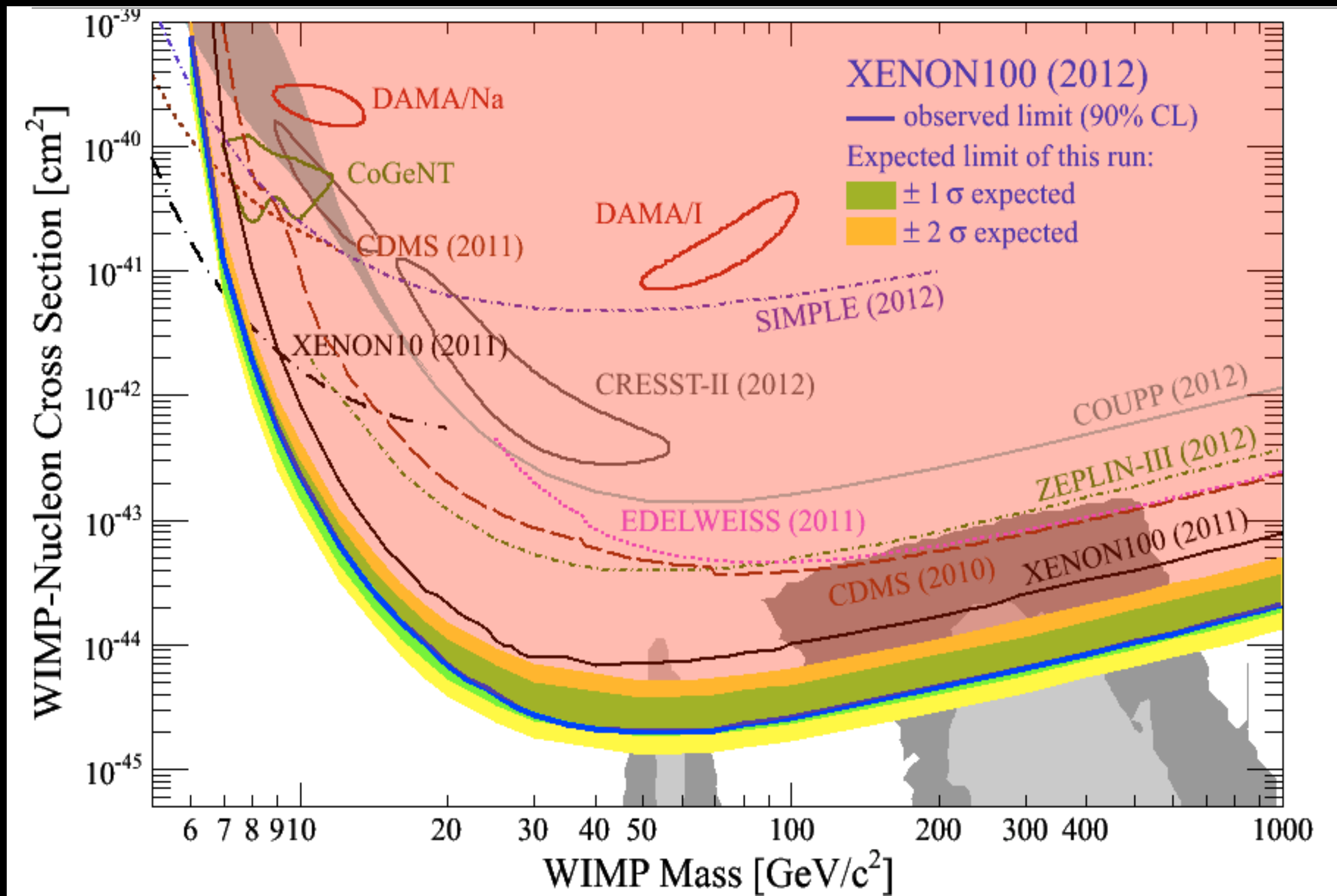


Aprile (for XENON-100 collab.), DarkAttack 2012

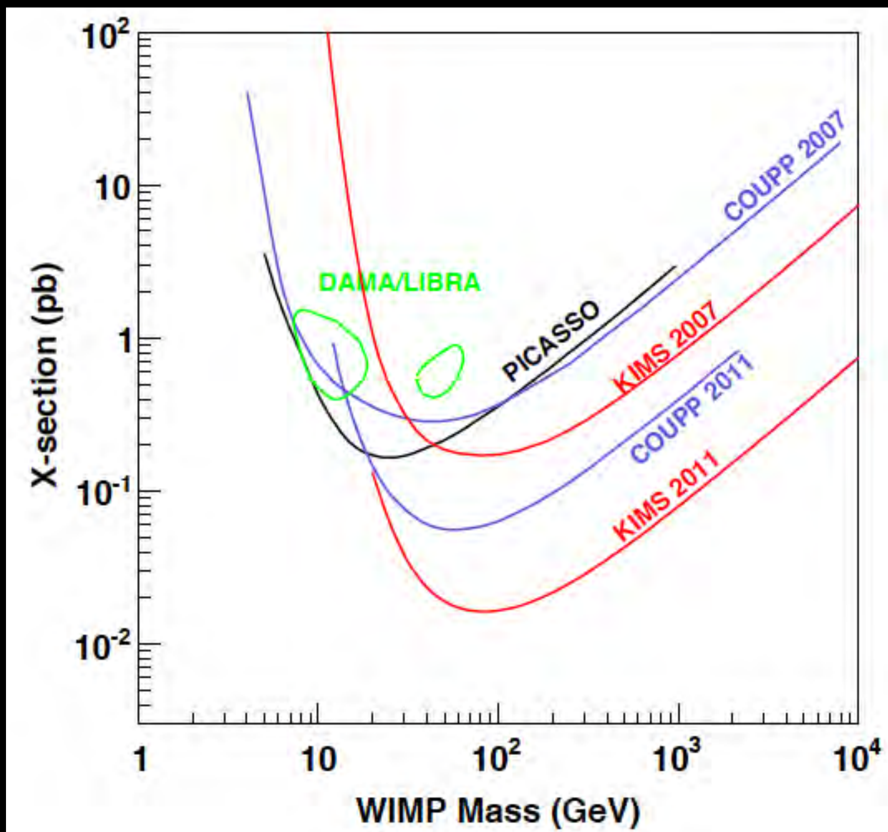
2 events observed

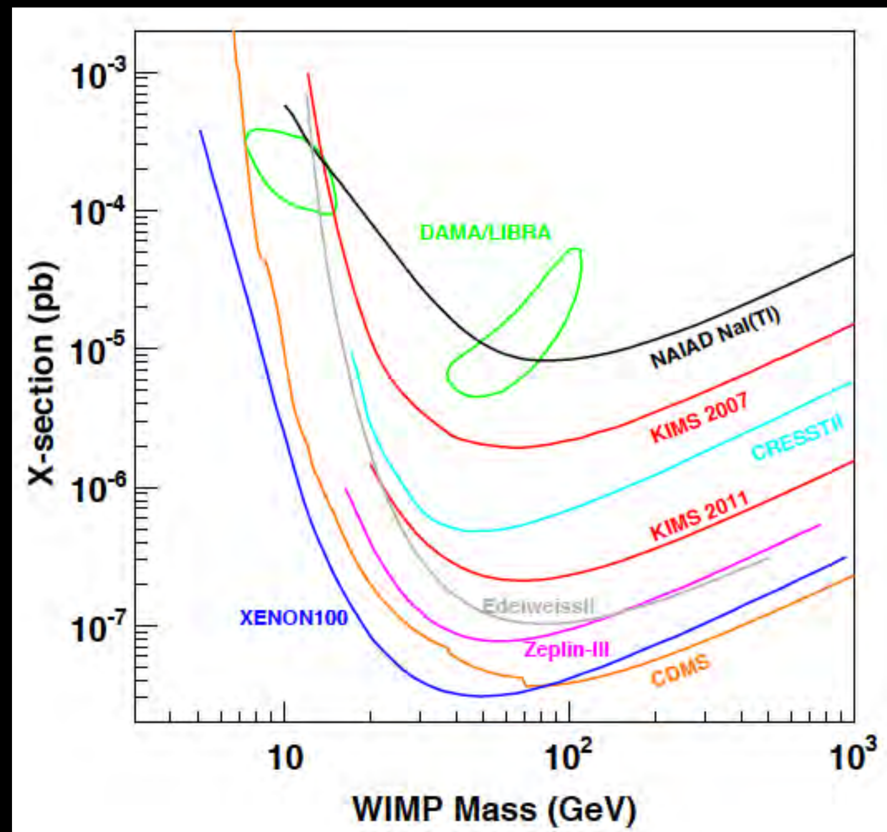
$0.79 \pm 0.16\ \gamma$ plus $0.17^{+0.12}_{-0.7}$ neutrons expected background

Limits from XENON-100, KIMS, CDMS, ...

KIMS: CsI scintillation detector
(similar to DAMA)

- *Excludes inelastic dark matter*
- *Excludes 60 GeV/c² DAMA region*

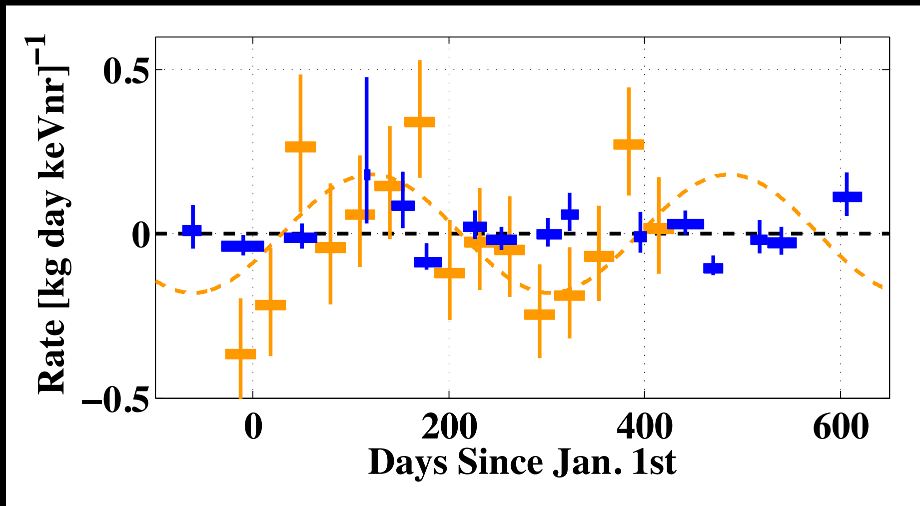




Without using detectors with large surface α background

Kim at TAUP 2011

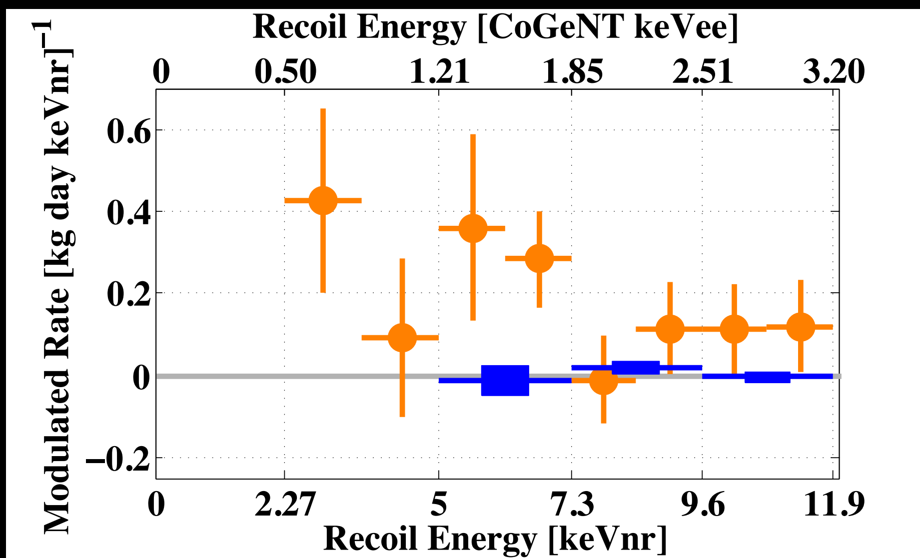
Limits from XENON-100, KIMS, CDMS, ...

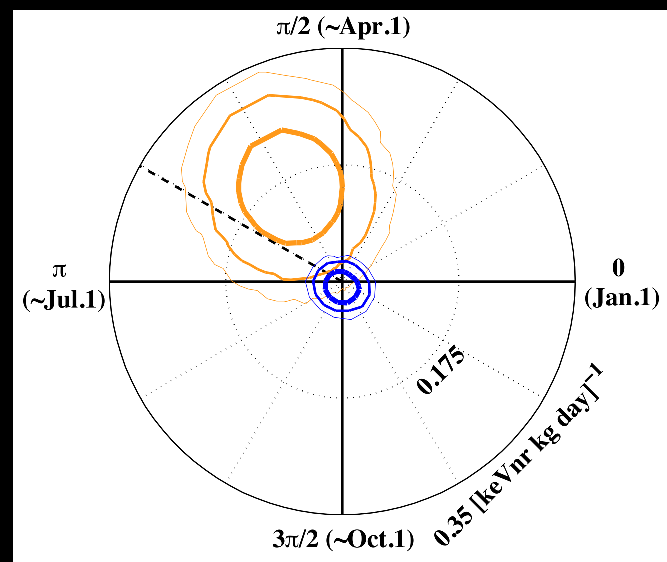


CDMS does not observe an annual modulation and constrains its amplitude

Ahmed et al 1203.1309

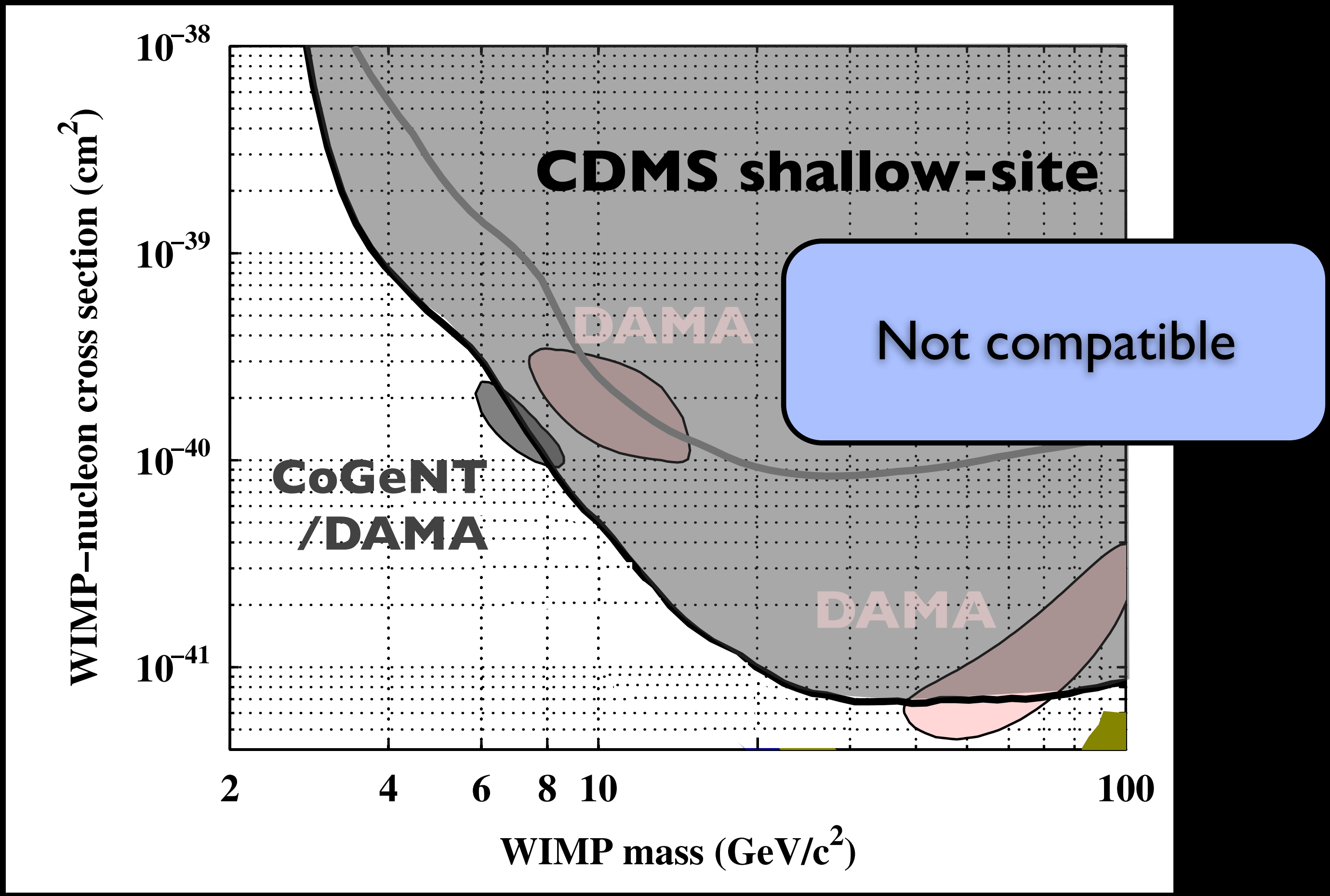
CoGeNT CDMS





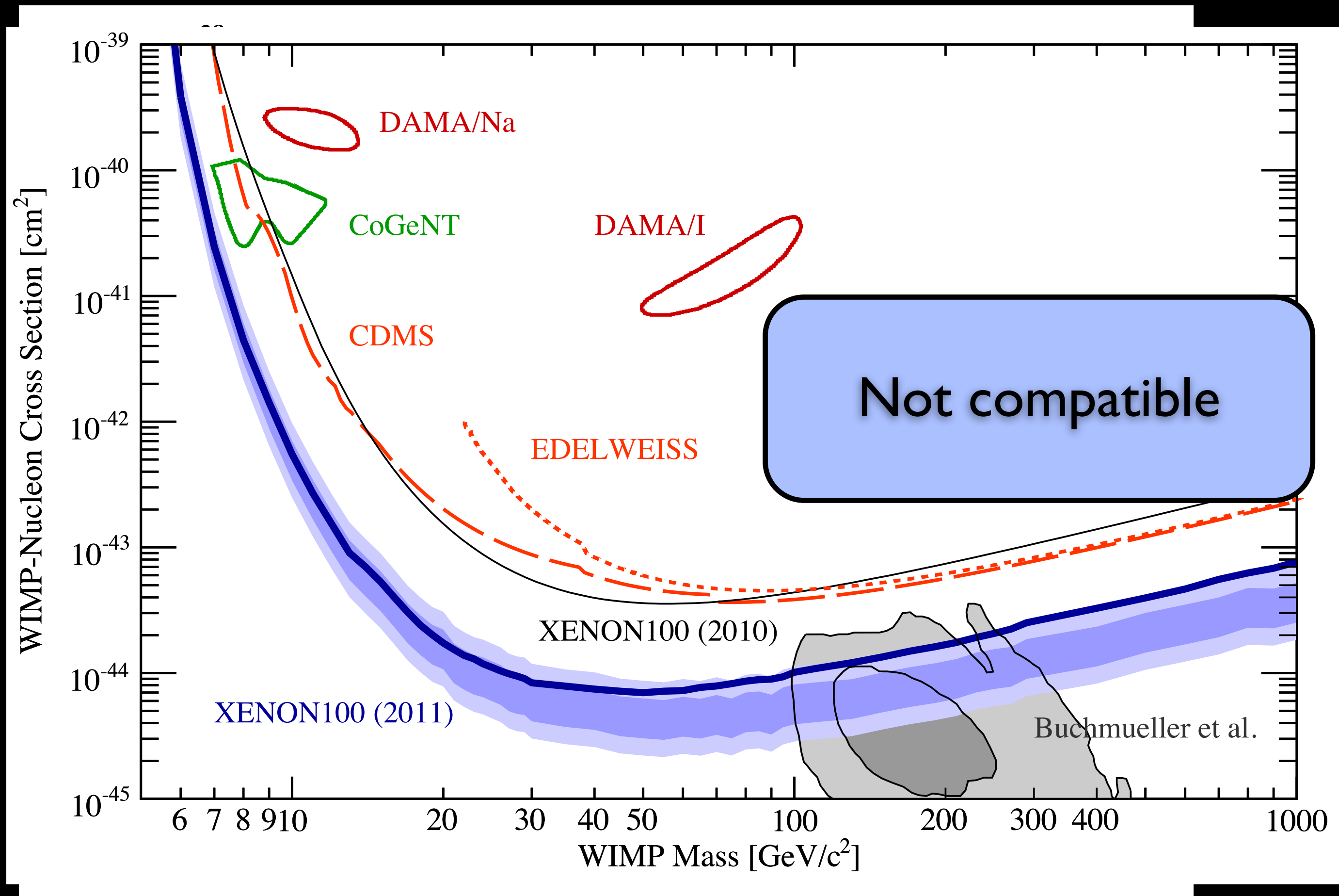
model-independent

CoGeNT & DAMA vs. XENON, CDMS, et al



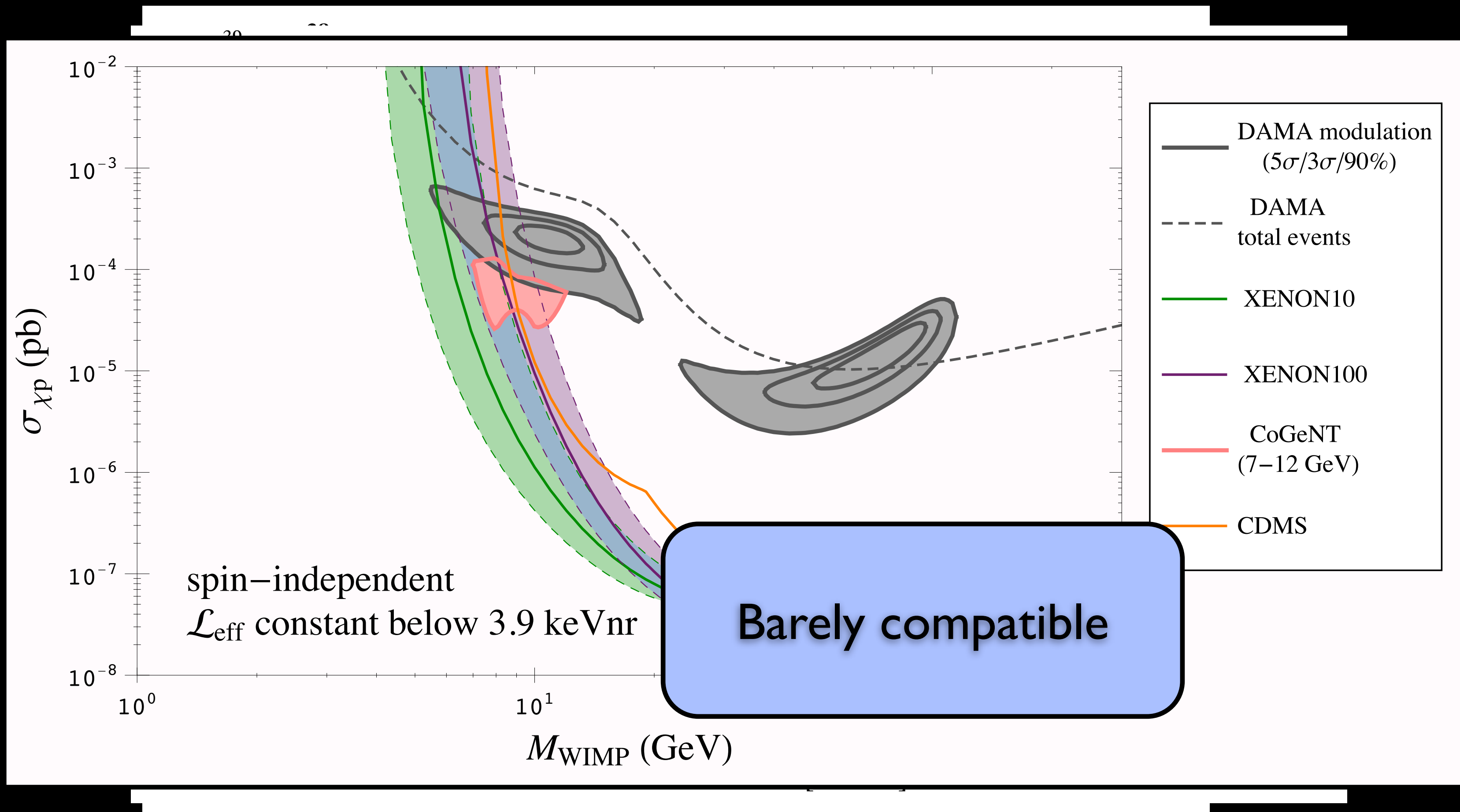
Akerib et al (CDMS) PRD82, 122004, 2010

CoGeNT & DAMA vs. XENON, CDMS, et al



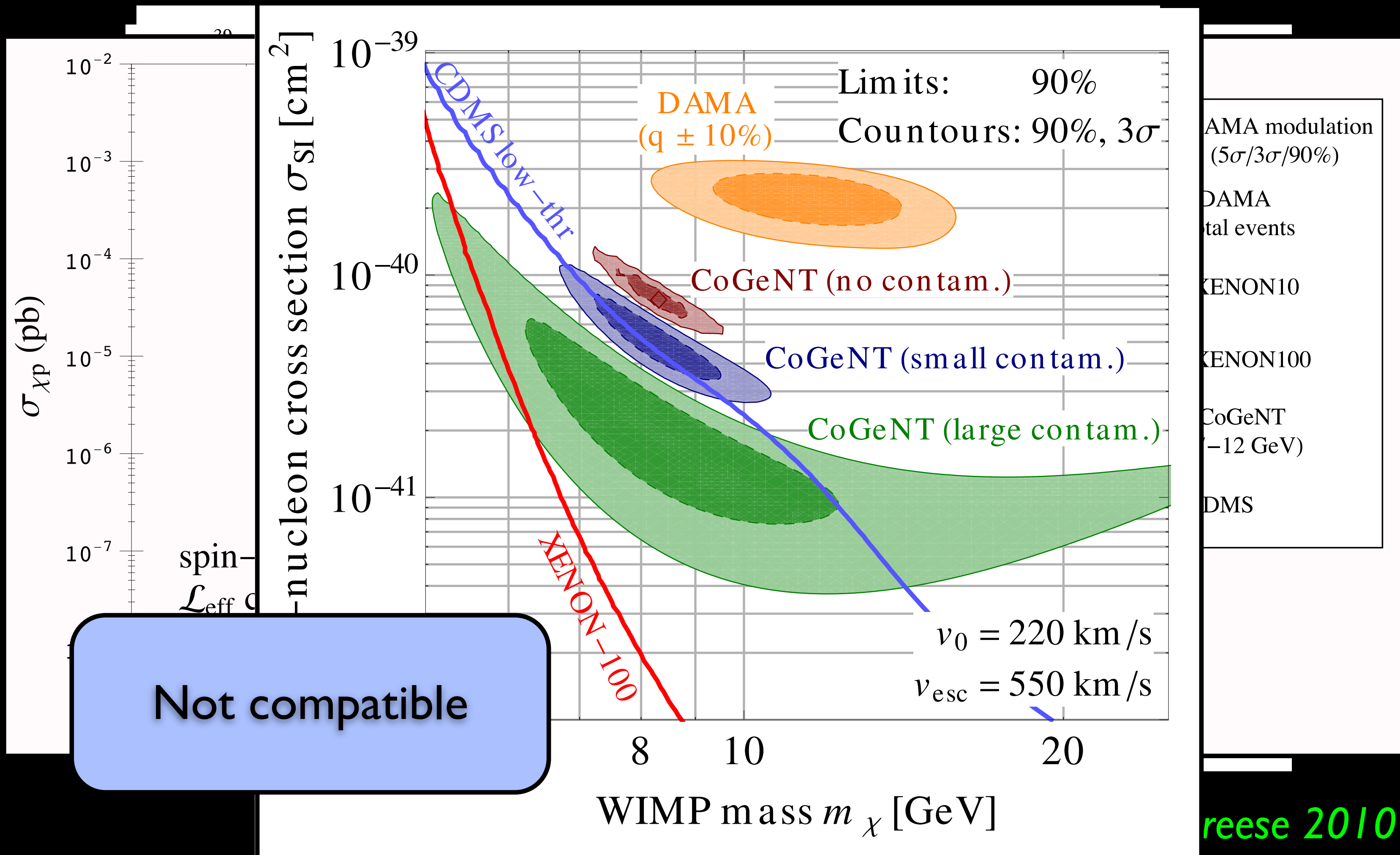
Aprile et al (XENON-100) 1104.2549

CoGeNT & DAMA vs. XENON, CDMS, et al



Savage, Gelmini, Gondolo, Freese 2010

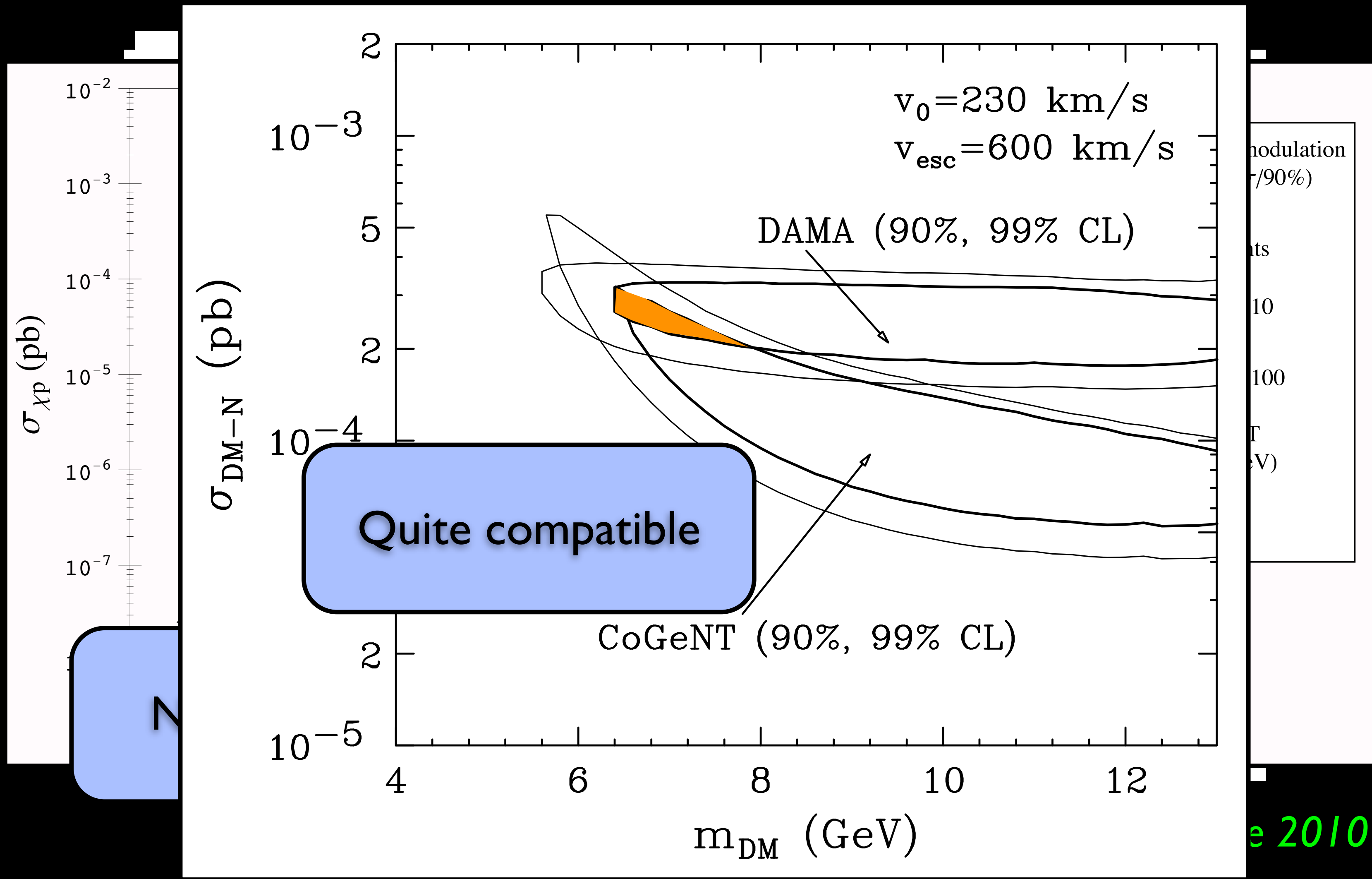
CoGeNT & DAMA vs. XENON, CDMS, et al



reese 2010

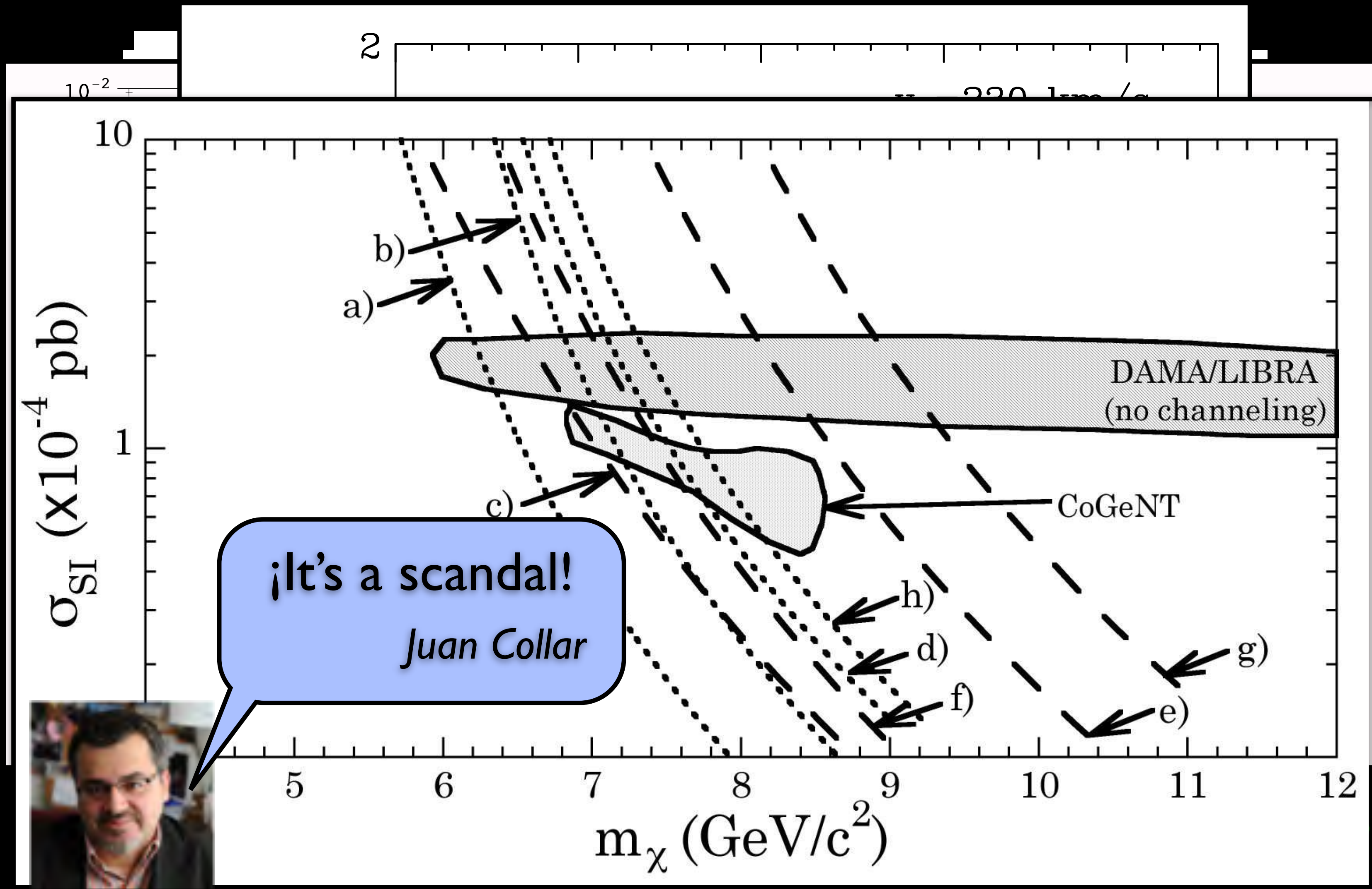
Kopp, Schwetz, Zupan 2011

CoGeNT & DAMA vs. XENON, CDMS, et al



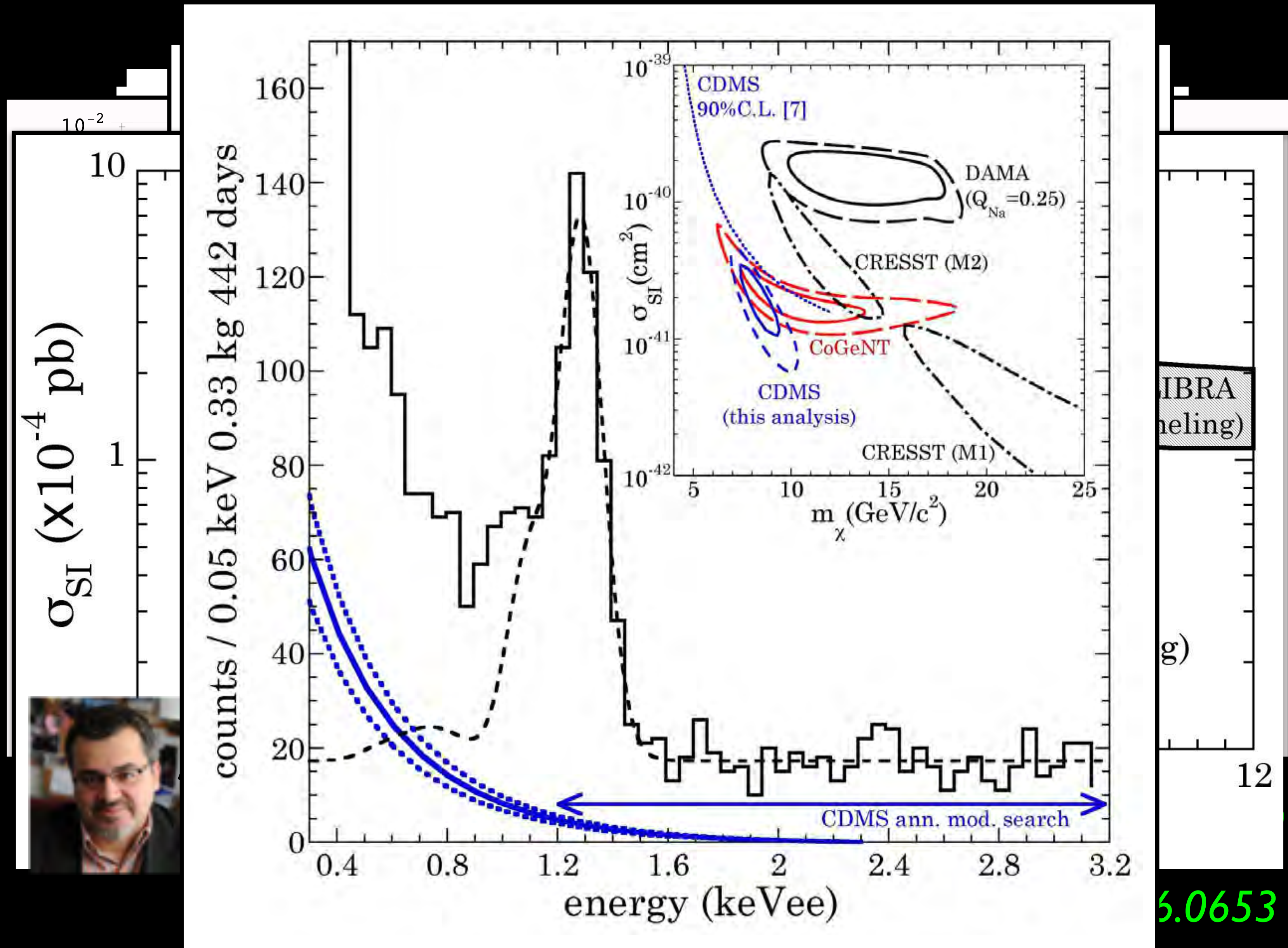
Hooper, Collar, Hall, McKinsey 2010

CoGeNT & DAMA vs. XENON, CDMS, et al



Collar 1106.0653

CoGeNT & DAMA vs. XENON, CDMS, et al



6.0653

Collar Fields 1204.3559

CoGeNT & DAMA vs. XENON, CDMS, et al

The comparison depends on the model!*

– astrophysics model

local density, velocity distribution

– particle physics model

mass, cross section (dependence on spin, velocity, energy, couplings)

– detector response model

energy resolution, quenching factors, channeling fraction

**Except for CoGeNT vs CDMS modulation*

Can limits be relaxed?

- Energy calibration?
  Collar (1106.0653v3) objects to scintillation and ionization yields. Hooper et al. fold in large uncertainties. Experimental issue. Efficiencies and energy resolution near threshold are essential: *paradoxically a worse energy resolution produces stronger bounds*.

- Large dependence on dark halo model?
  It should not affect CDMS, which has Ge as CoGeNT, but Xe is heavier, thus only sensitive to the high velocity WIMP tail, which may be missing: make a halo-independent analysis (Fox, Lie, Weiner 1011.1915; Frandsen et al 1111.0292; Gondolo, Gelmini 1202.6359)

- WIMP does not couple to Xe?
  $Z+(A-Z)(f_n/f_p)=0$, i.e. $f_n/f_p=-0.7$? "isospin-violating DM" (Kurylov, Kamionkowski 2003; Giuliani 2005; Cotta et al 2009; Chang et al 2010; Kang et al 2010; Feng et al 2011)

- Other?
  Inelastic DM, energy- or velocity-dependent form factor, ...?

The expected number of events

$$\begin{pmatrix}\text{number of}\\ \text{events}\end{pmatrix} = (\text{exposure}) \times \begin{pmatrix}\text{detector}\\ \text{response}\end{pmatrix} \otimes \begin{pmatrix}\text{recoil}\\ \text{rate}\end{pmatrix}$$

$$\begin{pmatrix}\text{detector}\\ \text{response}\end{pmatrix} = \begin{pmatrix}\text{energy}\\ \text{response function}\end{pmatrix} \times \begin{pmatrix}\text{counting}\\ \text{acceptance}\end{pmatrix}$$

$$\begin{pmatrix}\text{recoil}\\ \text{rate}\end{pmatrix} = \begin{pmatrix}\text{particle}\\ \text{physics}\end{pmatrix} \times (\text{astrophysics})$$

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$$\begin{pmatrix}\text{detector}\\ \text{response}\end{pmatrix} = \boxed{\begin{pmatrix}\text{energy}\\ \text{response function}\end{pmatrix}} \times \begin{pmatrix}\text{counting}\\ \text{acceptance}\end{pmatrix}$$

$$\begin{pmatrix}\text{recoil}\\ \text{rate}\end{pmatrix} = \begin{pmatrix}\text{particle}\\ \text{physics}\end{pmatrix} \times (\text{astrophysics})$$

Detector response model

From measured energy to recoil energy

$$\begin{pmatrix} \text{energy} \\ \text{response function} \end{pmatrix} = g(E_{\text{ee}}, E)$$

Recoil energy (keV)

Energy observed in detector, typically expressed in keV electron equivalent (keV_{ee})

Typically written as a single Gaussian with mean value

$$E_{\text{ee}} = Q E$$

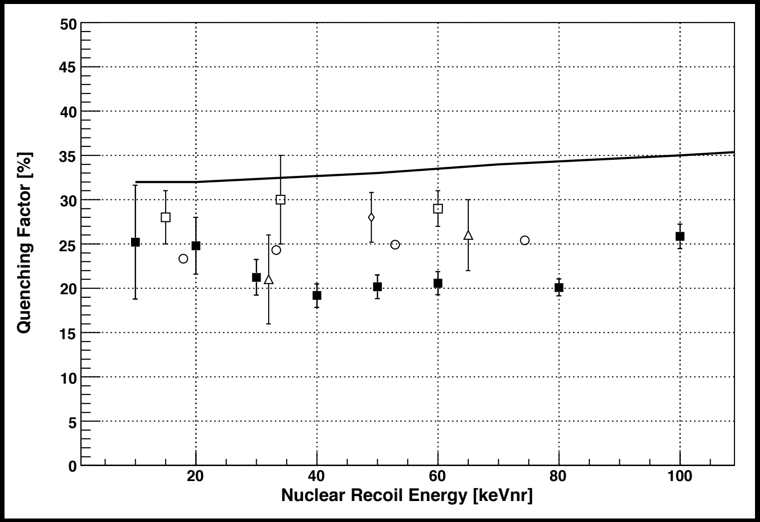
Quenching factor

and standard deviation σ_E, but *may be different.*

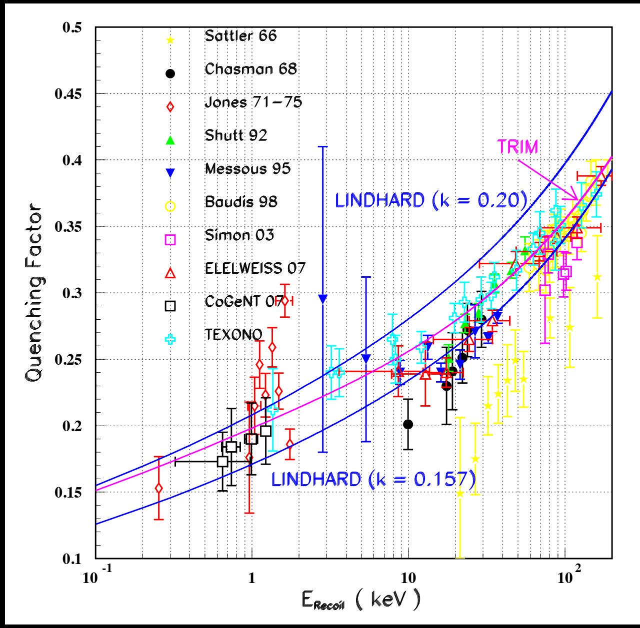
Detector response model

Quenching factor $E_{ee} = \boxed{Q} E$

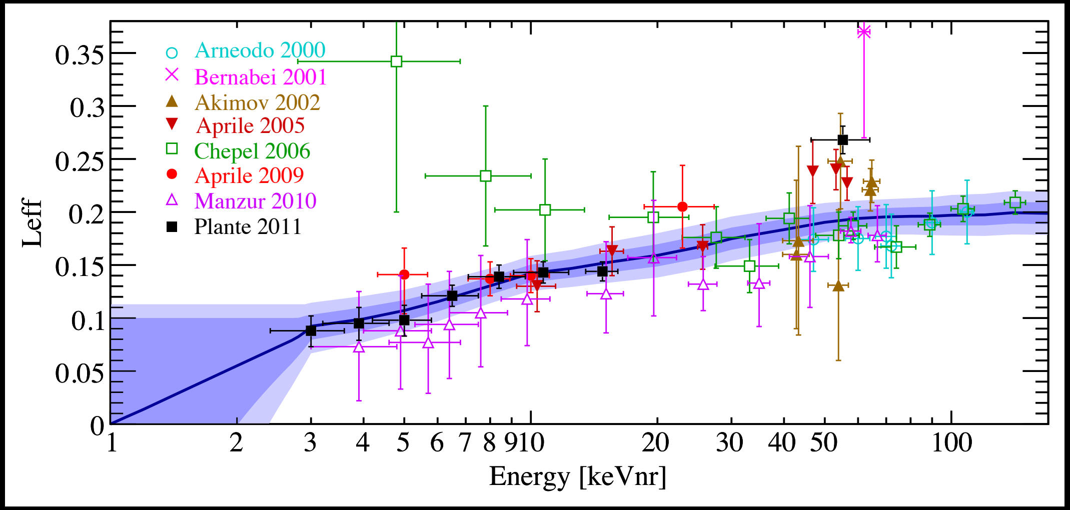
Chagani et al 0806.1916



This is where one can tweak to make experiments compatible.



Lin et al (TEXONO) 2007



Aprile et al (XENON100), 1104.2549

Detector response model

Channeling

Quenching factor depends on direction of recoil

Monochromatic ^{16}O beam through NaI(Tl) scintillator

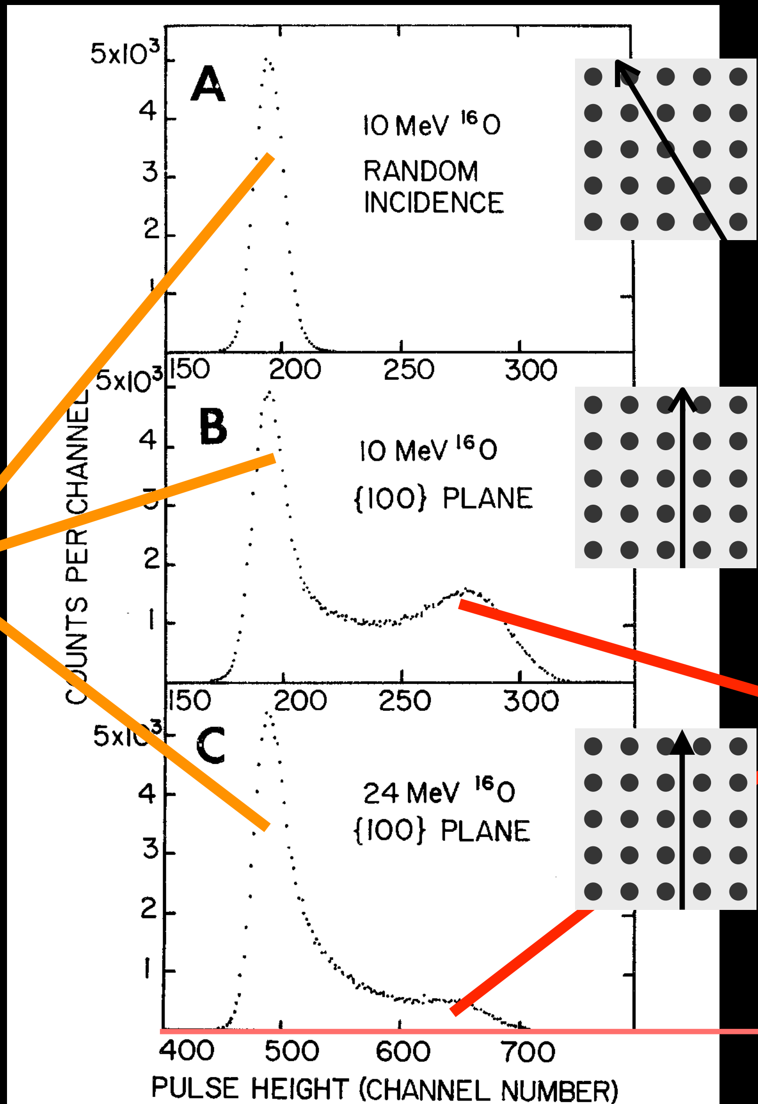


FIG. 2. (a) Pulse-height spectrum from 10-MeV ^{16}O on NaI(Tl) for incidence along a random direction. (b) Pulse-height spectrum from 10-MeV ^{16}O along a {100} plane. (c) Pulse-height spectrum from 24-MeV ^{16}O along a {100} plane. A light guide was used in all cases.

Not channeled

Channeled

Scintillation output

Altman et al 1973 (Phys.Rev. B7, 1743)

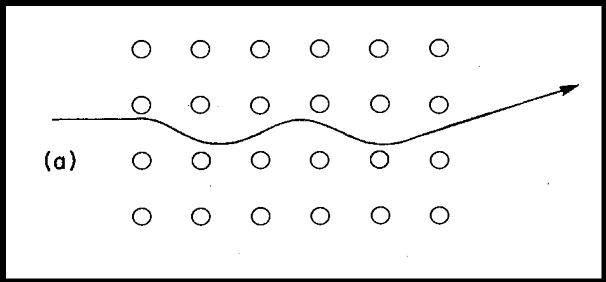
Detector response model

Fraction of channeled recoils

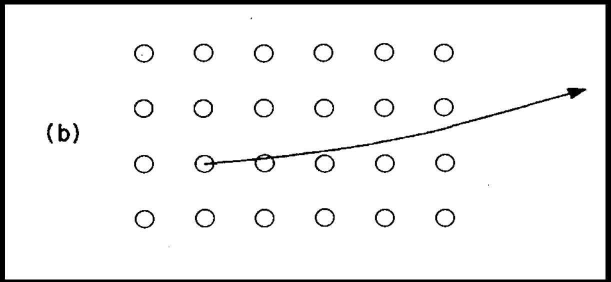
Very small because of blocking

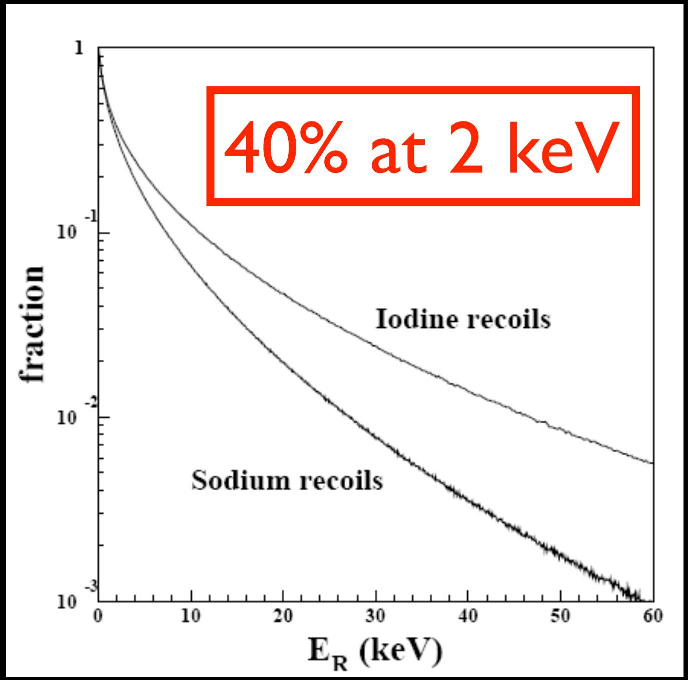
Channeling

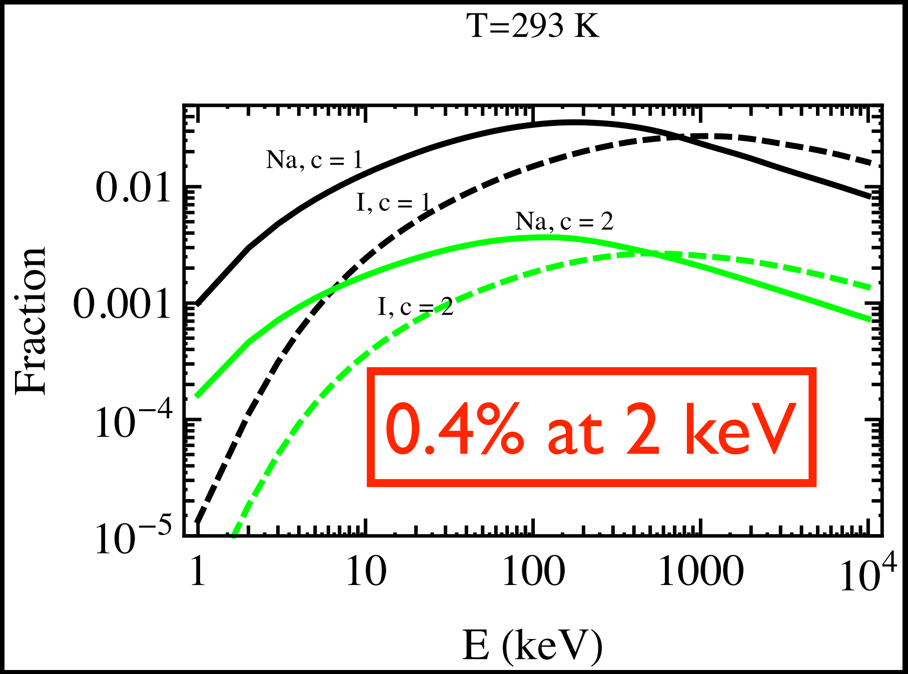
Blocking



The recoiling nucleus belongs to the lattice







Bernabei et al. 2008

Bozorgnia, Gelmini, Gondolo 2010

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Astrophysics model

How much dark matter comes to Earth?

Local halo density

Velocity distribution

$$(\text{astrophysics}) = \rho \int_{v>v_{\min}(E)} \frac{f(\vec{v},t)}{v}\, \mathrm{d}^3 v$$

Minimum speed to impart energy E, $v_{\min}(E) = (ME/\mu + \delta)/\sqrt{2ME}$

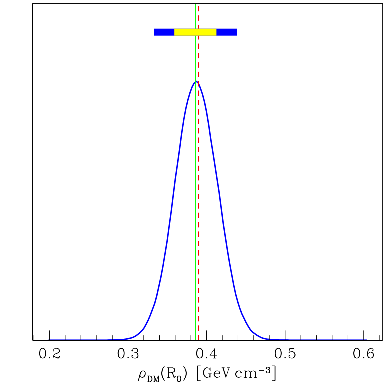
Astrophysics model: local density

$$\rho_\odot = \left(0.430 \pm 0.113_{(\alpha_\odot)} \pm 0.096_{(r_{\odot D})}\right)\frac{\text{GeV}}{\text{cm}^3}\,.$$

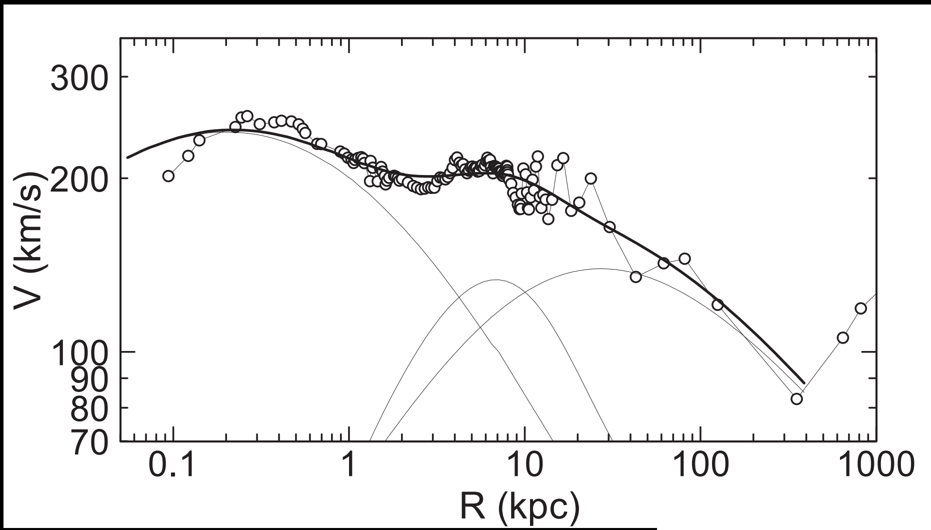
Salucci et al 2010

$$\rho_{DM}(R_0) = 0.385 \pm 0.027\,\text{GeV cm}^{-3}$$

Ullio, Catena 2009

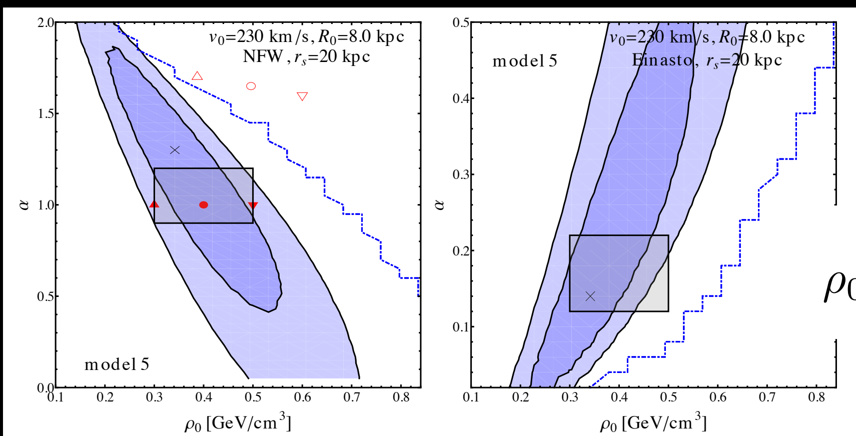


Local density from galactic modeling



Sofue 2011

$$\rho_0^\odot = 0.235 \pm 0.030 \text{ GeV cm}^{-3}$$



$$\rho_0 = 0.20 - 0.55 \text{ GeV/cm}^3$$

Iocco, Pato, Bertone, Jetzer 2010

Astrophysics model: local density

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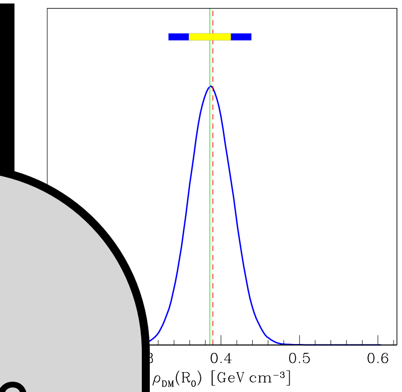


Lo

gal

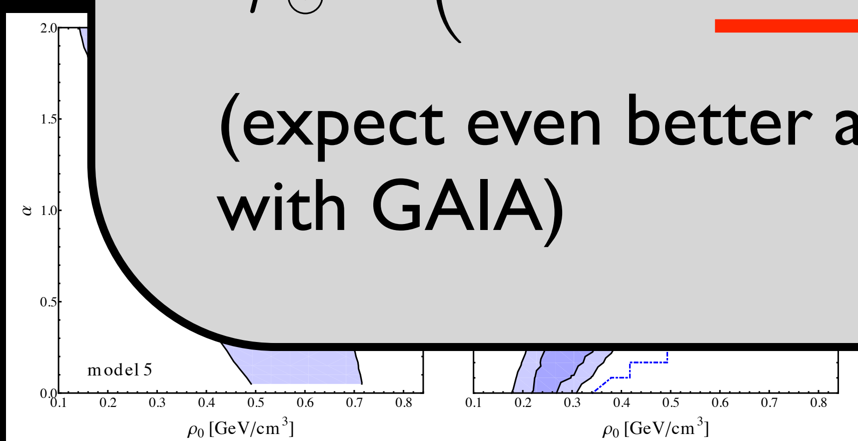
The most direct method, requiring only local measurements of the disk contribution and the slope of rotation curve at the Sun's distance. Now even more precise with preliminary VERA

$$\rho_\odot = \left(0.463 \pm 0.044_{(\alpha_\odot)} \pm 0.096_{(r_{\odot D})}\right)\frac{\text{GeV}}{\text{cm}^3}$$

(expect even better at VERA completion and with GAIA)

Honma at NDM12

cm^{-3}



Iocco, Pato, Bertone, Jetzer 2010

Astrophysics model: velocity distribution

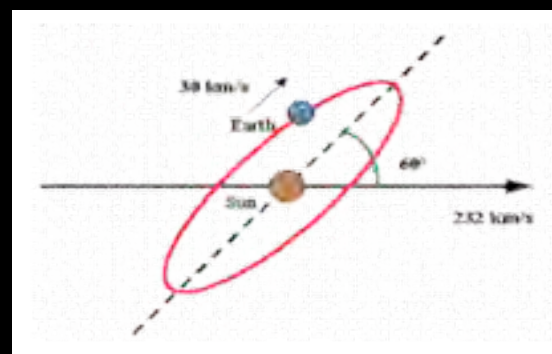
The velocity factor $\eta(E,t) = \int_{v>v_{\rm min}(E)} \frac{f(\vec{v},t)}{v}\, \mathrm{d}^3 v$

- If $f(E,t)$ is non-truncated Maxwellian in detector frame, $\eta(E,t)$ is exponential in E

- $\eta(E,t)$ depends on time (unless WIMPs move with detector)

Example: annual modulation

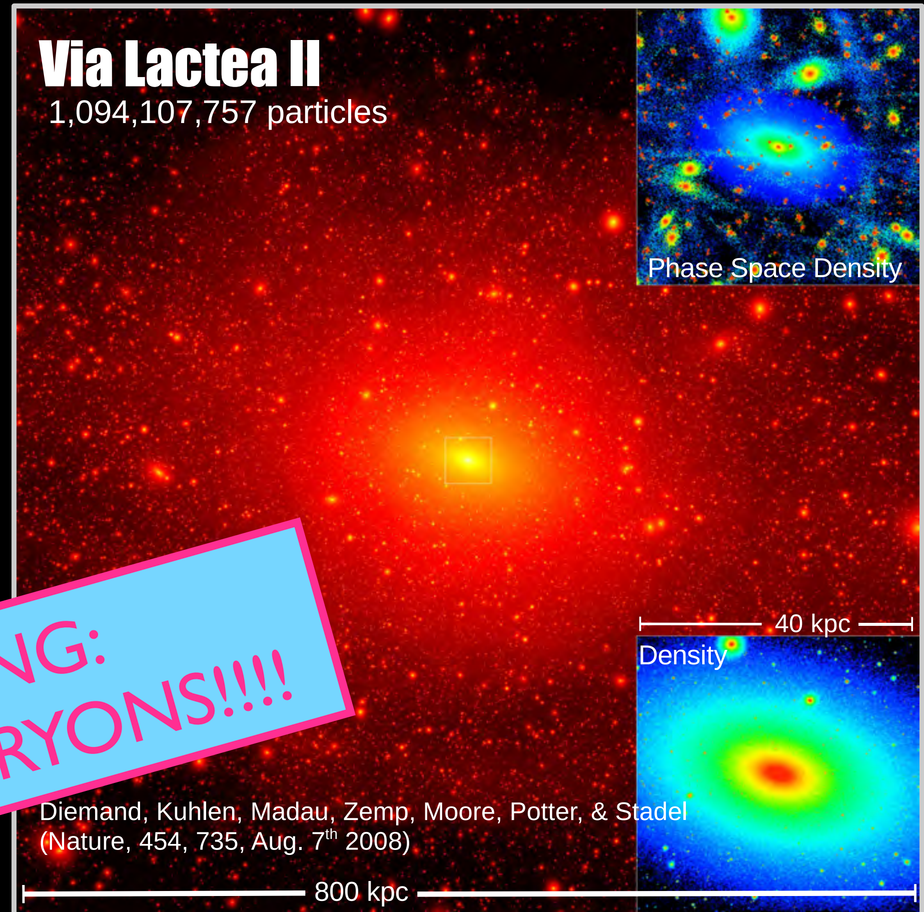
$$\eta(E,t) = \eta_0(E) + \eta_{\rm m}(E) \cos\omega(t - t_0)$$



Drukier, Freese, Spergel 1986

Astrophysics model

Cosmological
N-body
simulations



WARNING:
NO BARYONS!!!!

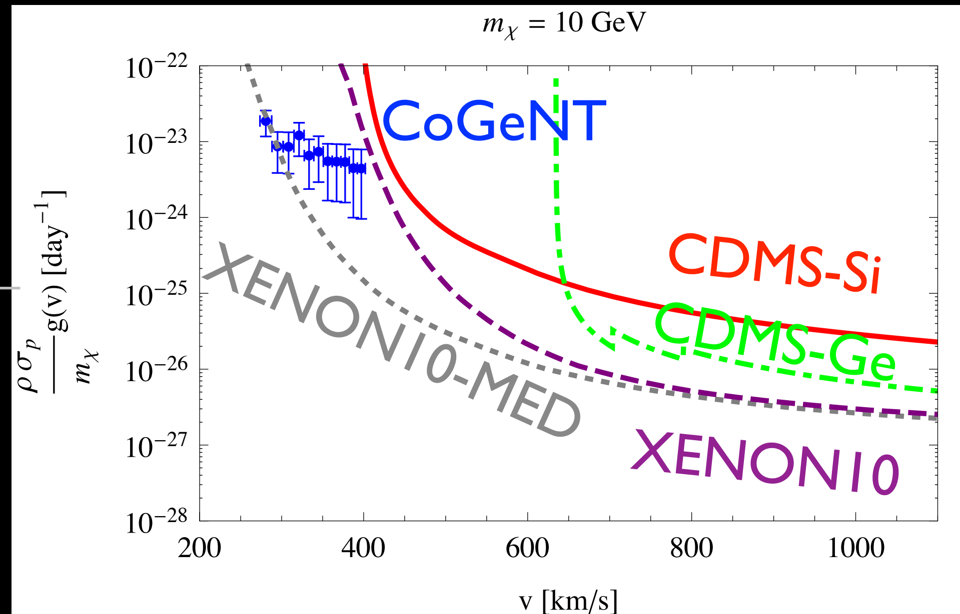
But see Kuhlen (this conference) for simulations including baryons

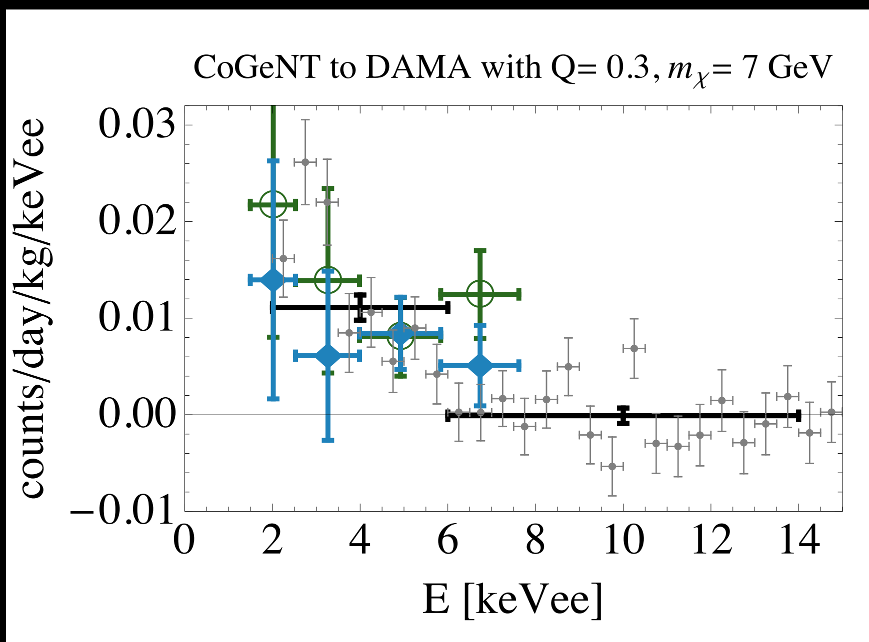
Astrophysics-independent approach

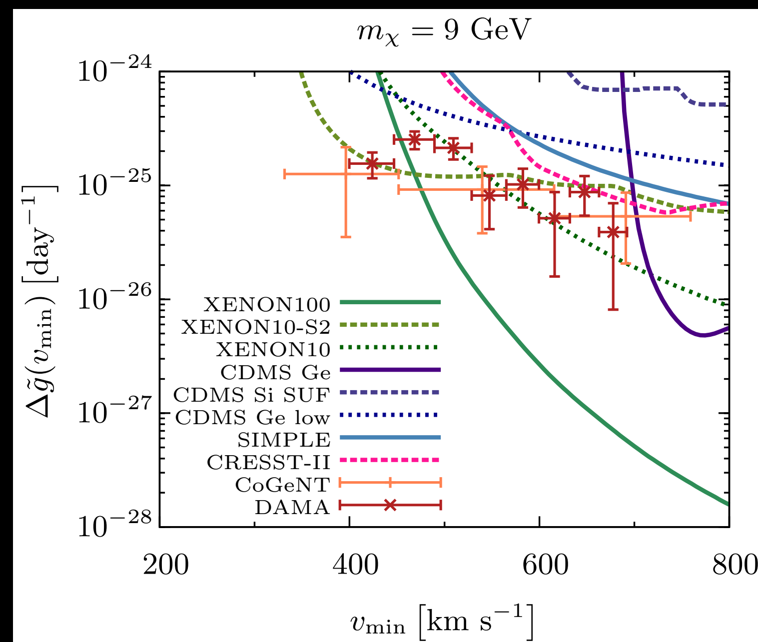
Fox, Liu, Weiner 2011

Astrophysics factor

$$\frac{\rho_\chi \sigma_{\chi p} c^2}{m_\chi} \int_v^\infty \frac{f(v')}{v'} dv'$$



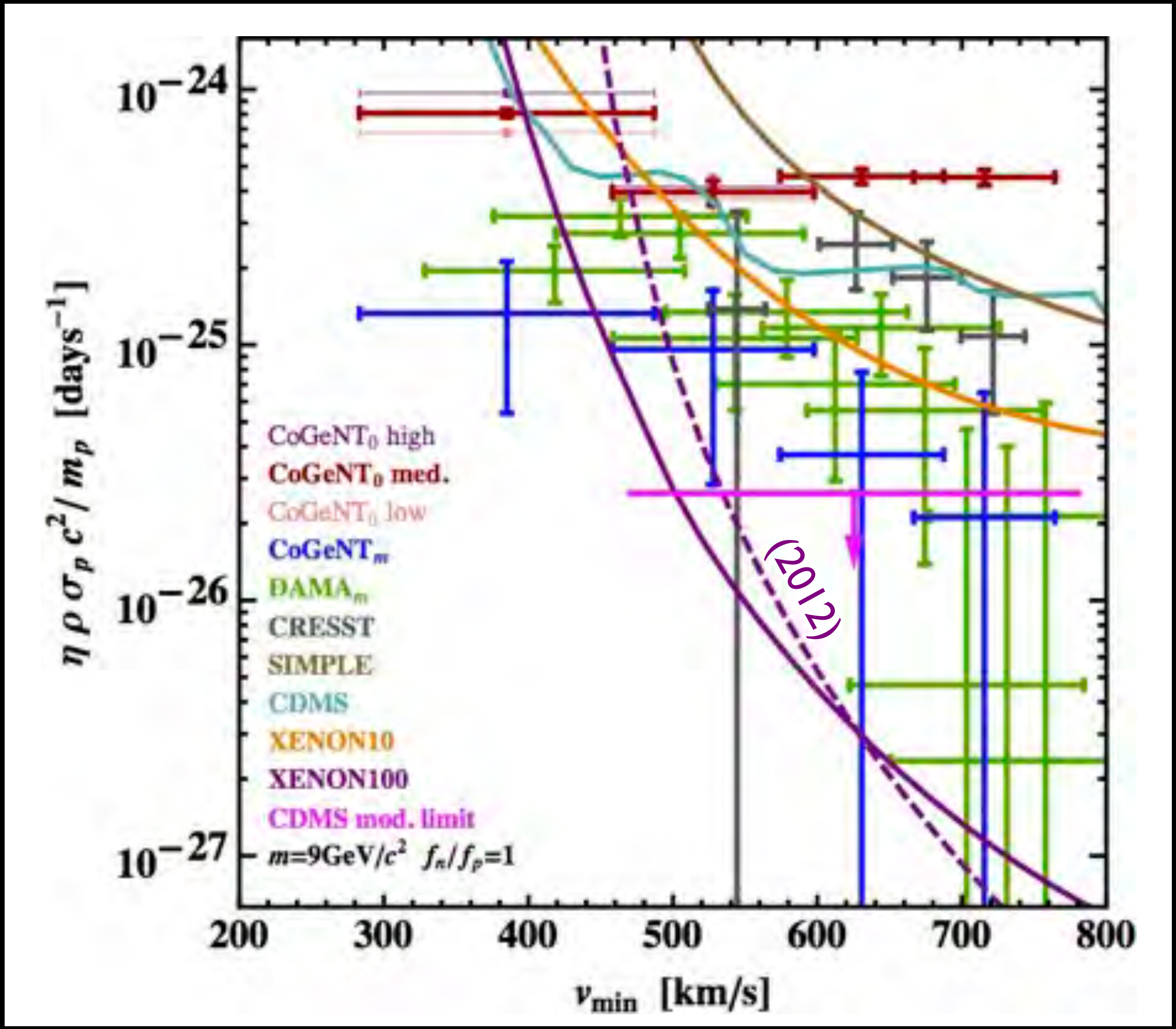




Fox, Kopp, Lisanti, Weiner 2011

Frandsen et al 2011

Astrophysics-independent approach



Analysis extends Fox, Liu, Weiner method to include energy response function

Halo modifications alone cannot save the SI signal regions from the Xe bounds

Still depends on particle model

Updated from Gondolo Gelmini 1202.6359

Conclusions

Conclusions

None.

Conclusions

None.

Confusion

Maximal.