Hints of dark matter mass from DM searches?

Jong-Chul Park
(KIAS)

June 30, 2011

Outline

- Dark matter
- Direct searches
- Indirect searches
- Conclusion

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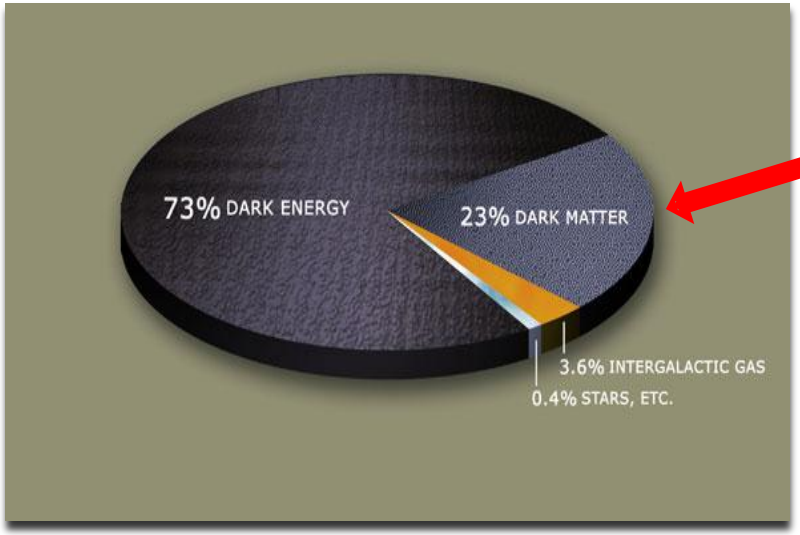
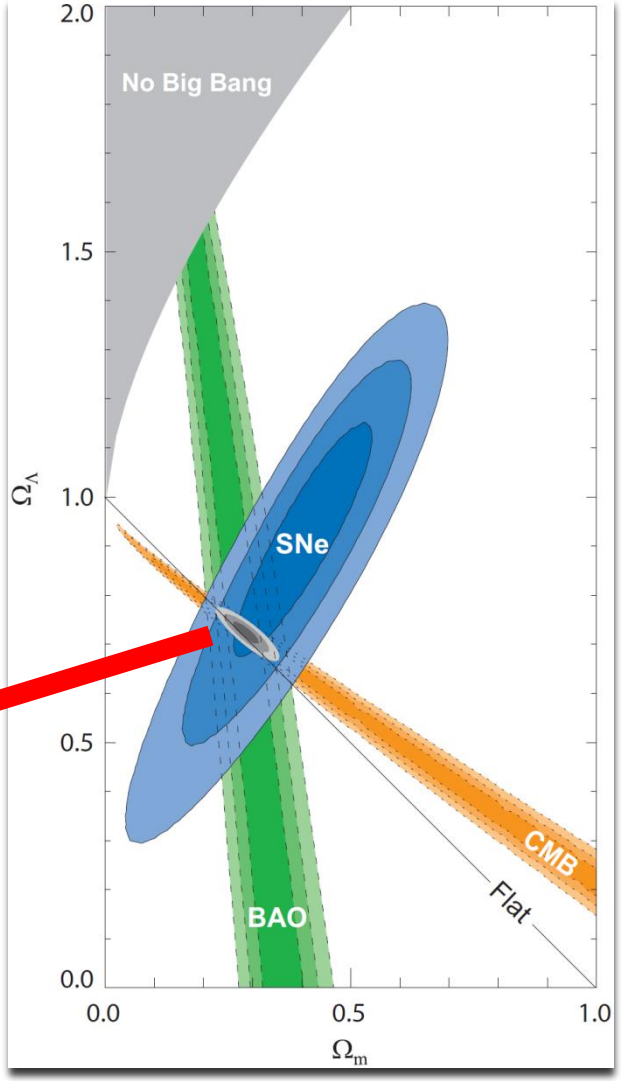
Why dark matter?

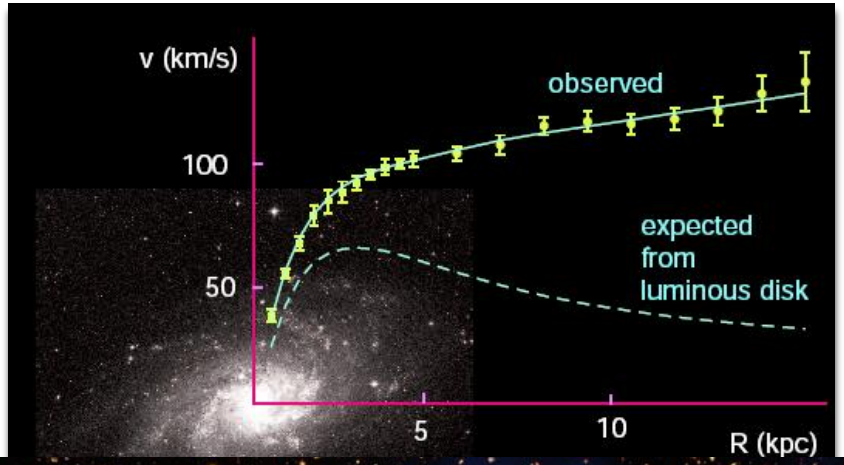
Dark matter

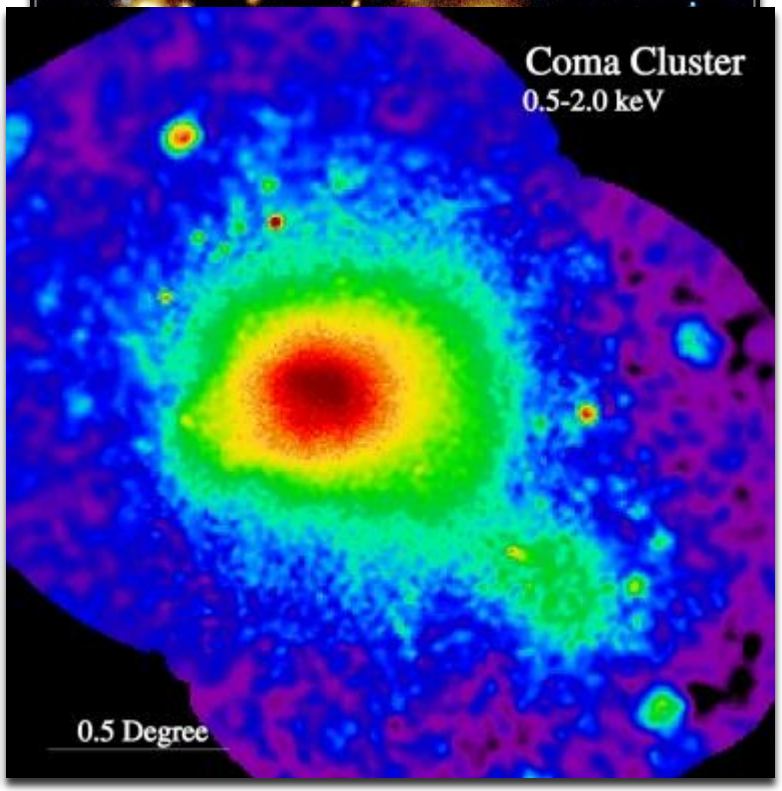
- postulated by Fritz Zwicky in 1930's
  to explain missing mass of the Coma cluster
- a conjectured form of matter:
  undetectable by electromagnetic radiation
  presence can be inferred from gravitational effects
- accounts for 23% of the total mass-energy of the Universe





Observational evidence of DM





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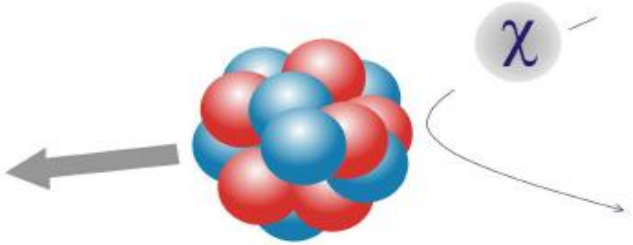
DM direct detection

local DM flux: $\phi_\chi \sim 10^5\,\mathrm{cm}^{-2}\mathrm{s}^{-1} \left(\frac{100\,\mathrm{GeV}}{m_\chi}\right) \left(\frac{\rho_\chi}{0.4\,\mathrm{GeV\,cm}^{-3}}\right)$

assuming DM has non-gravitational interactions ("WIMP")
look for recoil of DM-nucleus scattering M. Goodman, E. Witten, PRD 1985



cnts / keV recoil energy E_R:

$$\frac{dN}{dE_R}(t) \propto \frac{\rho_\chi}{m_\chi} \int_{v>v_{\min}} d^3v \, \frac{d\sigma}{dE_R} \, v \, f_\oplus(\vec{v}, t)$$

ρ_χ DM energy density, default: 0.3 GeV cm^{-3}
$v_{\min}$: minimal DM velocity required to produce recoil energy E_R

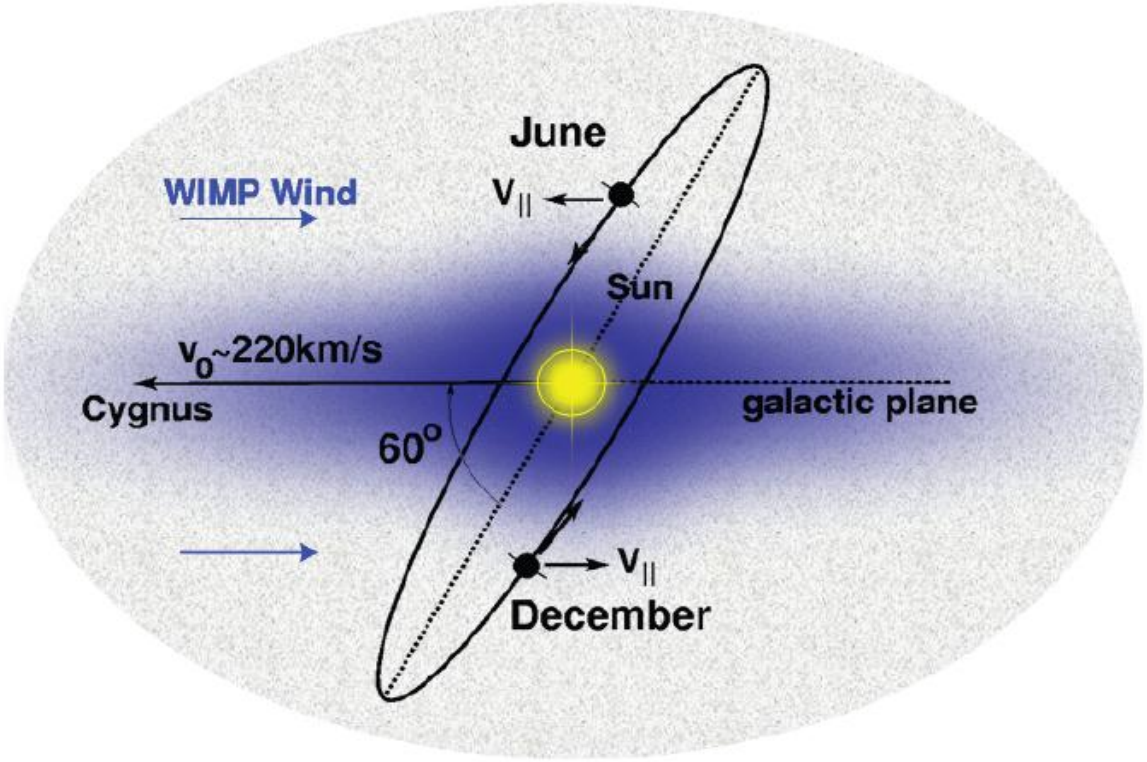
DM velocity distribution

$$f_\oplus(\vec{v},t) = f_{\rm gal}(\vec{v}+\vec{v}_\odot+\vec{v}_\oplus(t)) \qquad f_{\rm gal}(\vec{v}) \approx \begin{cases} N\exp\left(-v^2/\bar{v}^2\right) & v < v_{\rm esc} \\ 0 & v > v_{\rm esc} \end{cases}$$

$\bar{v} \simeq 220\,{\rm km/s}$ $\quad v_{\rm esc} \simeq 550\,{\rm km/s}$

sun velocity: $\vec{v}_\odot = (0,220,0) + (10,13,7)\,{\rm km/s}$

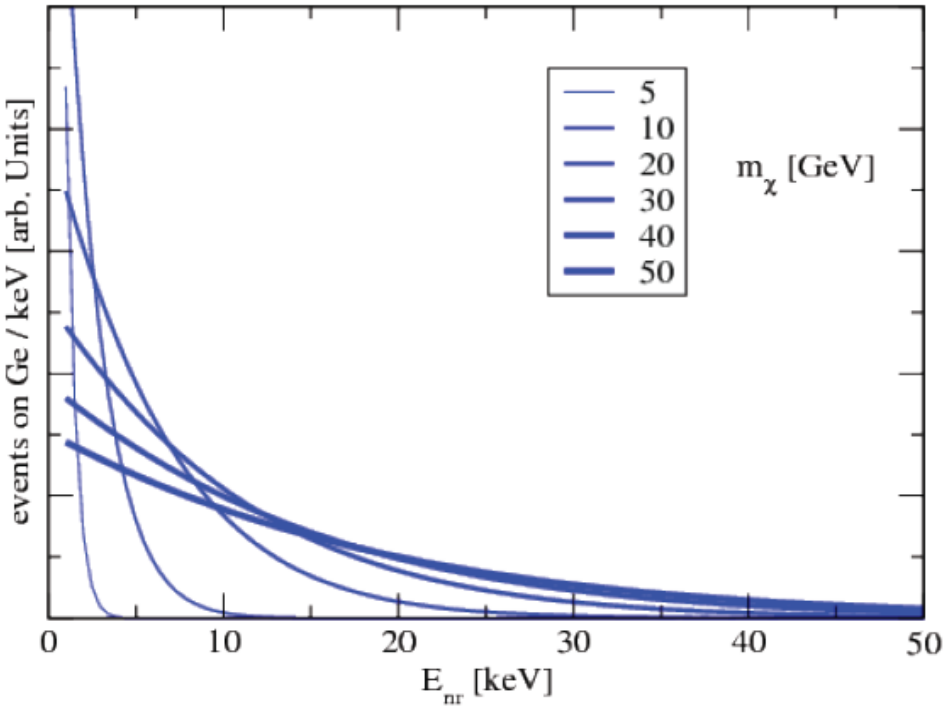
earth velocity: $\vec{v}_\oplus(t)$ with $v_\oplus \approx 30\,{\rm km/s}$



Event spectrum

$$\frac{dN}{dE_R}(t) = \frac{\rho_\chi}{m_\chi} \frac{\sigma_p |F(q)|^2 A^2}{2\mu_p^2} \int_{v>v_{\min}(E_R)} d^3v \frac{f_\oplus(\vec{v}, t)}{v}$$

$v_{\min} = \frac{m_\chi + M}{m_\chi} \sqrt{\frac{E_R}{2M}}$: minimal DM velocity needed for recoil energy E_R



$m_\chi \ll M$:

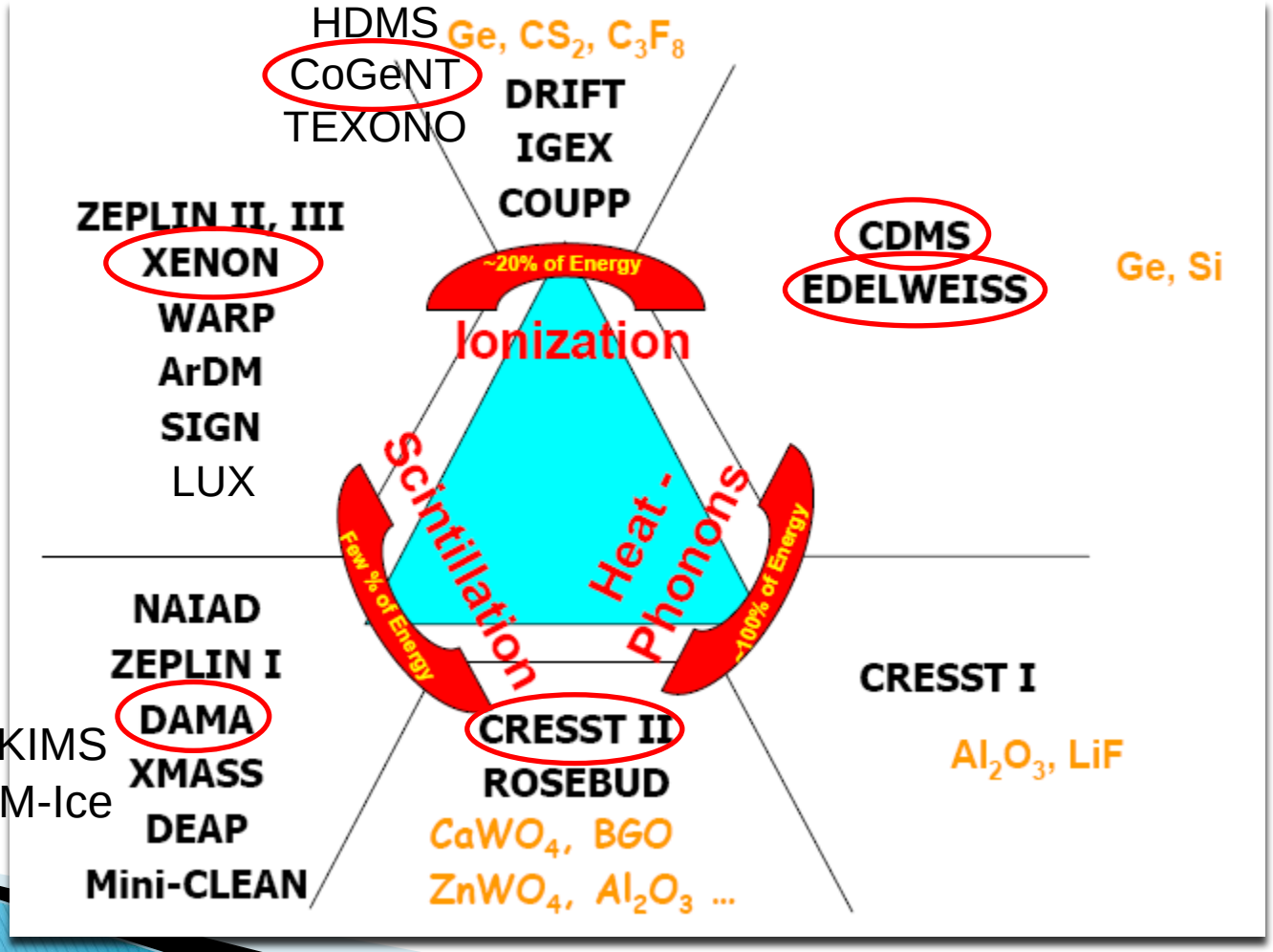
$$v_{\min} \approx \frac{\sqrt{ME_R/2}}{m_\chi}$$

spectrum gets shifted to low energies for low WIMP masses

$\Rightarrow$ energy threshold is crucial

DM direct detection

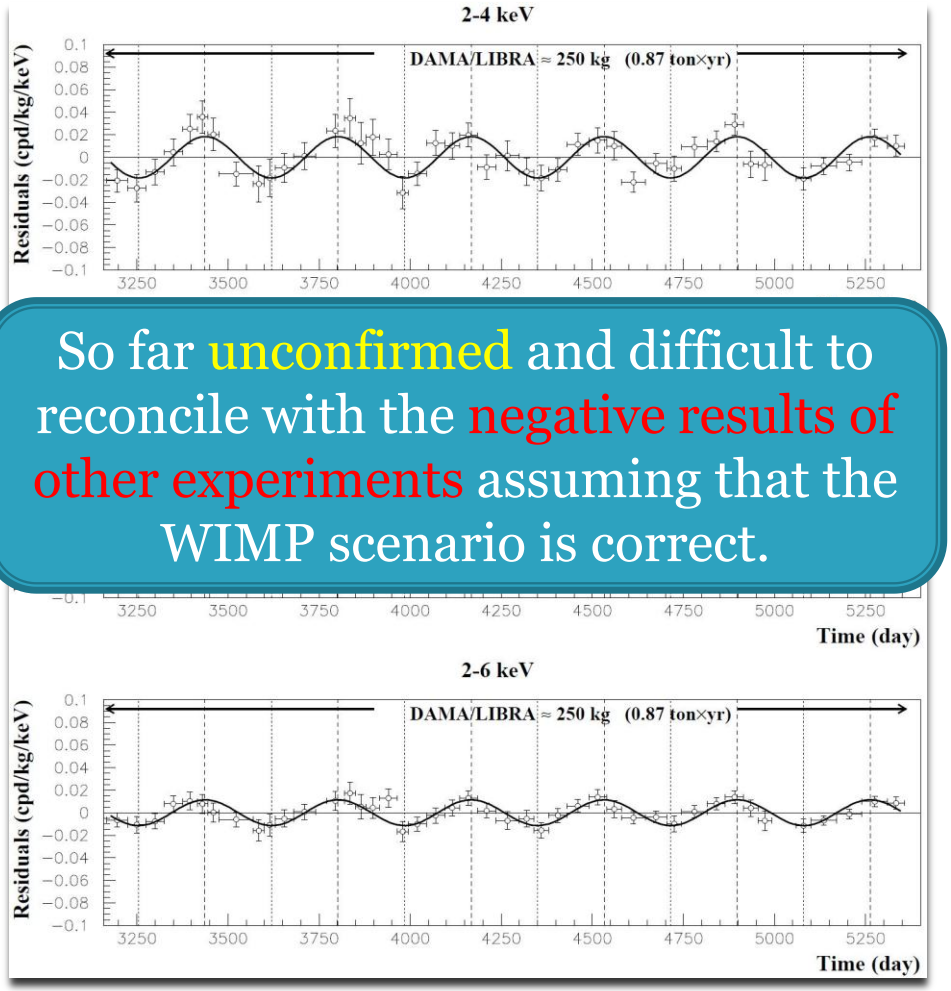
❖ Recently, some direct detection experiments reported **interesting results**.



DAMA: Annual modulation?

EPJ C67, 39 (2010)

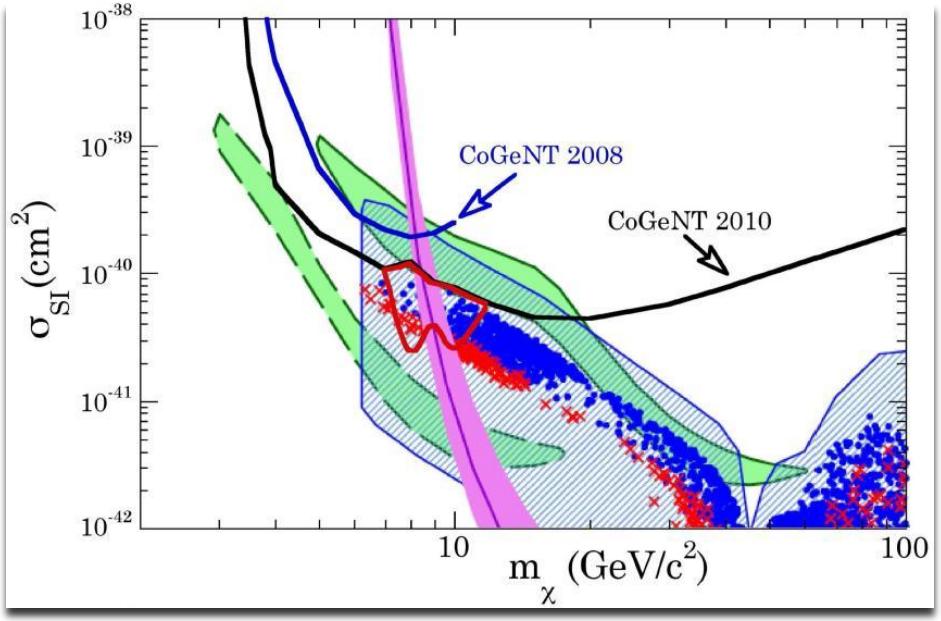
- NaI target
- As the Earth orbits the Sun, the velocity of the detector relative to the DM halo varies.
- DAMA has detected an annual modulation in the event rate (8.9 σ C.L.)
- 13 annual cycles
- Modulation amplitude: 0.0116 ± 0.0013
- Phase: 146 ± 7 days (cf. June 2nd)
- Period: 0.999 ± 0.002 yr



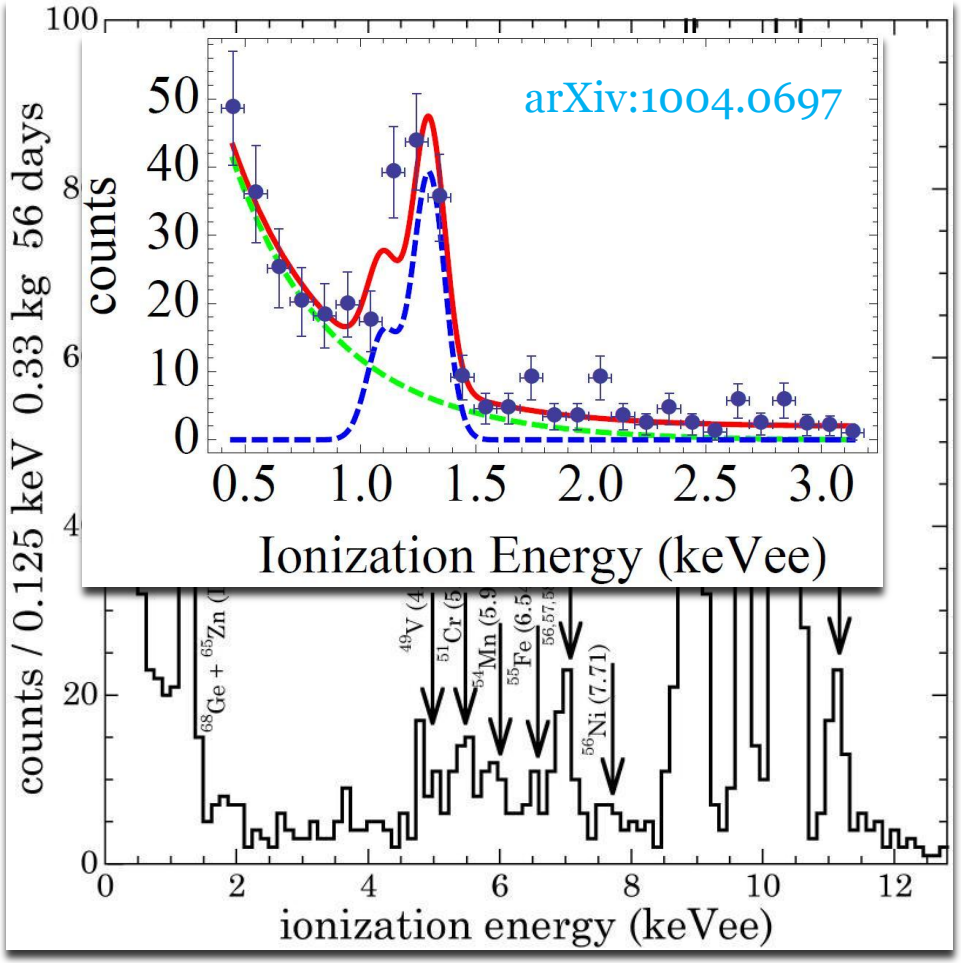
So far unconfirmed and difficult to reconcile with the negative results of other experiments assuming that the WIMP scenario is correct.

CoGeNT result I

- Ge target
- CoGeNT observed the low-energy rise in a PPC spectrum.
- Light (6-12 GeV) WIMPs provide a good fit to the data.

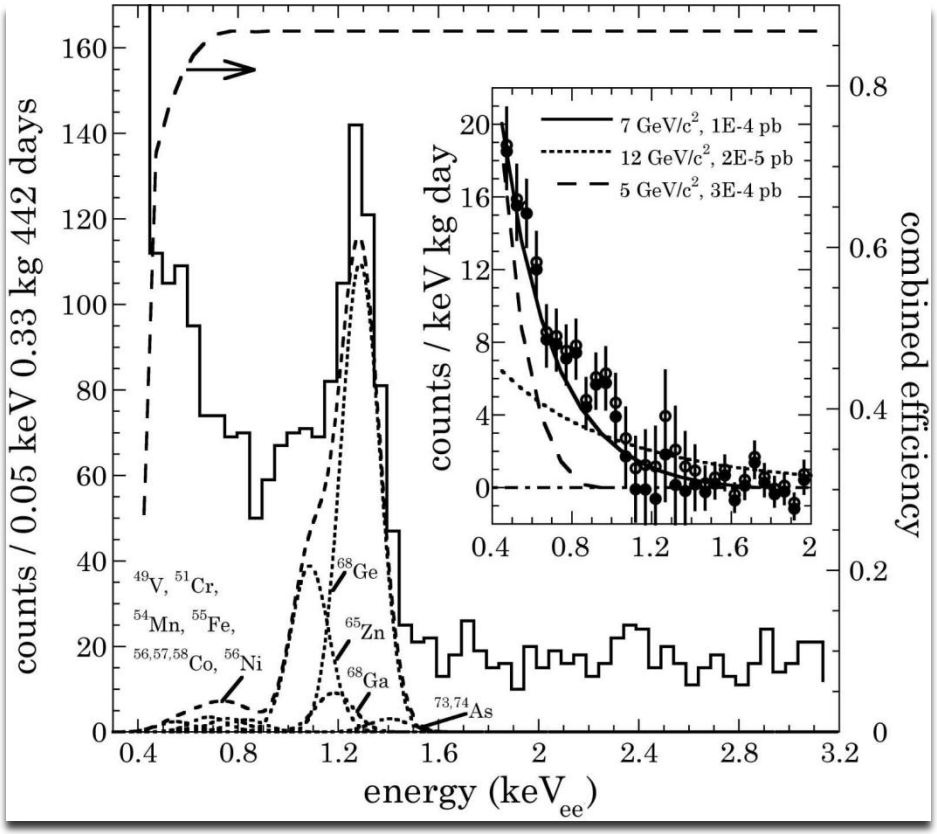


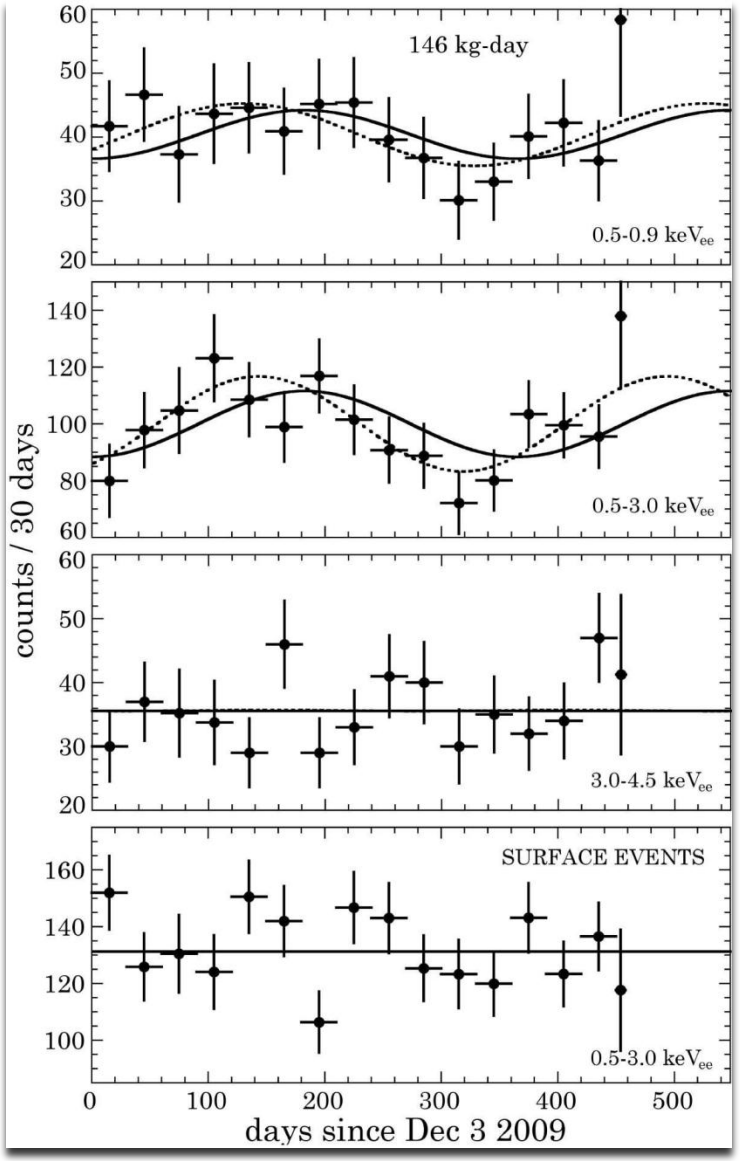
arXiv:1002.4703



CoGeNT result II

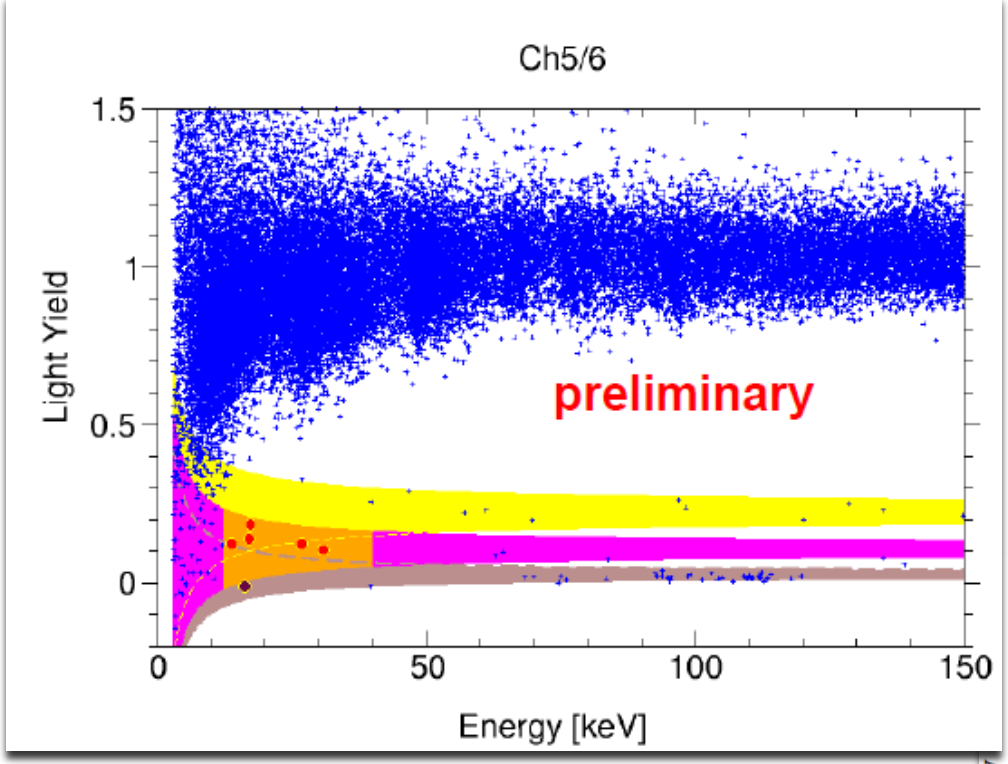
- Hint for annual modulation?





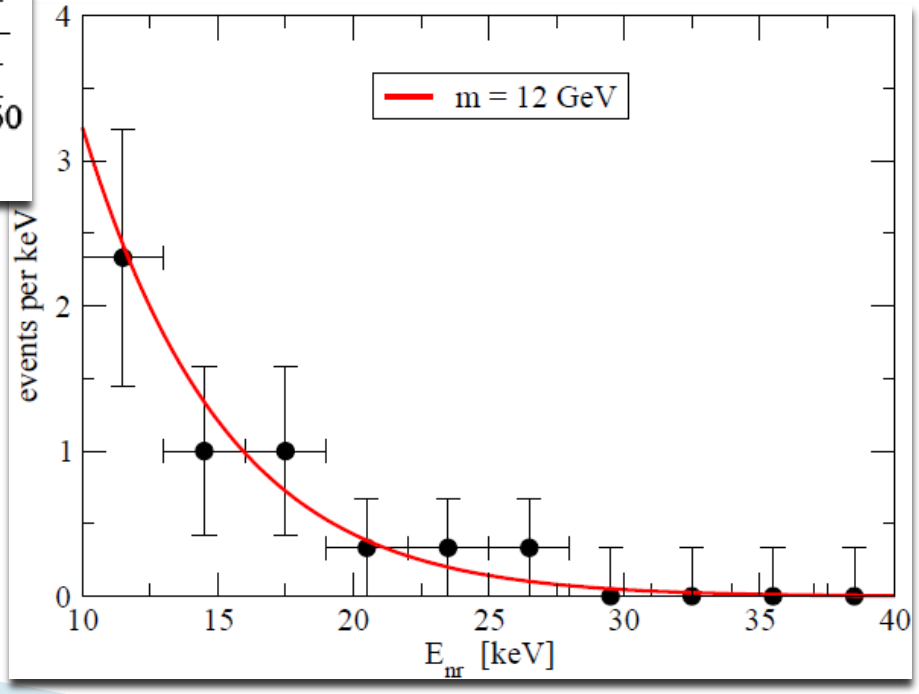
arXiv:1006.0650

CRESST

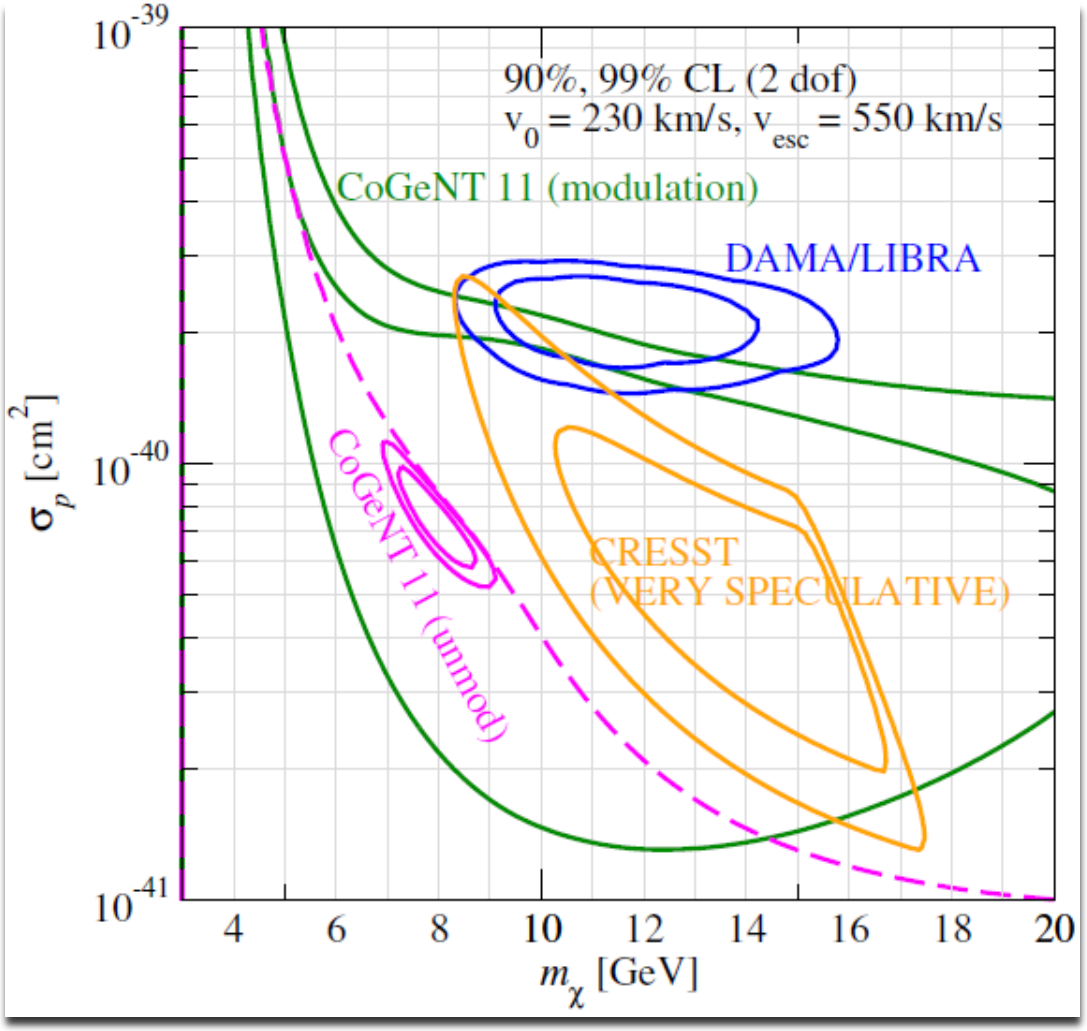


- Each contains 300g $CaWO_4$ crystal
- 32 events , 8.7 ± 1.4 background

- What is going on in the O band?
- α-leakage? Neutrons?
- Something new?
  - ⇒ Low mass WIMPs??
- More statistics is needed.



10 GeV DM?

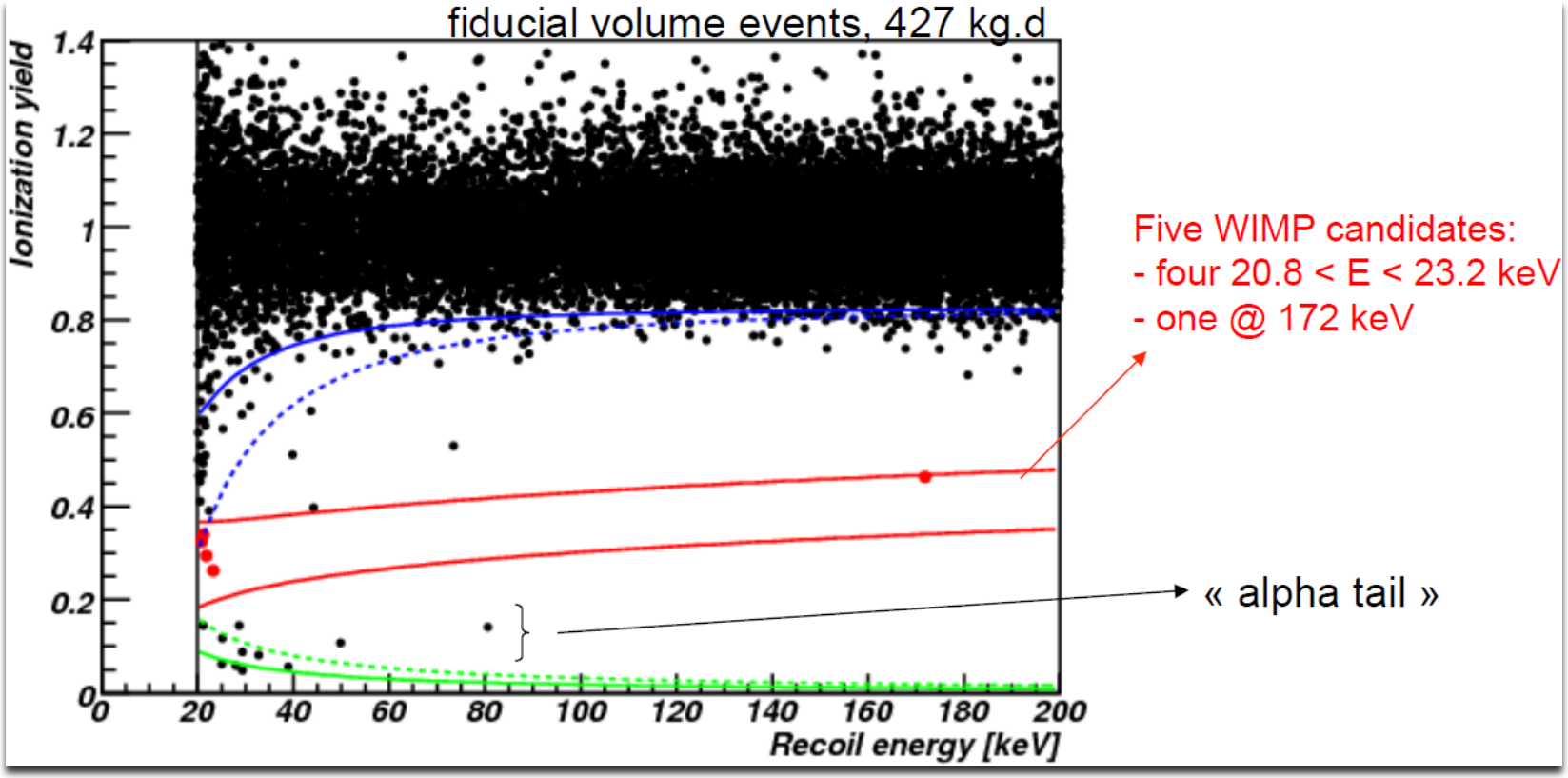


Schwetz, PPC 2011

EDELWEISS

- Ge target
- 5 events passed all the cuts, background < 3.0

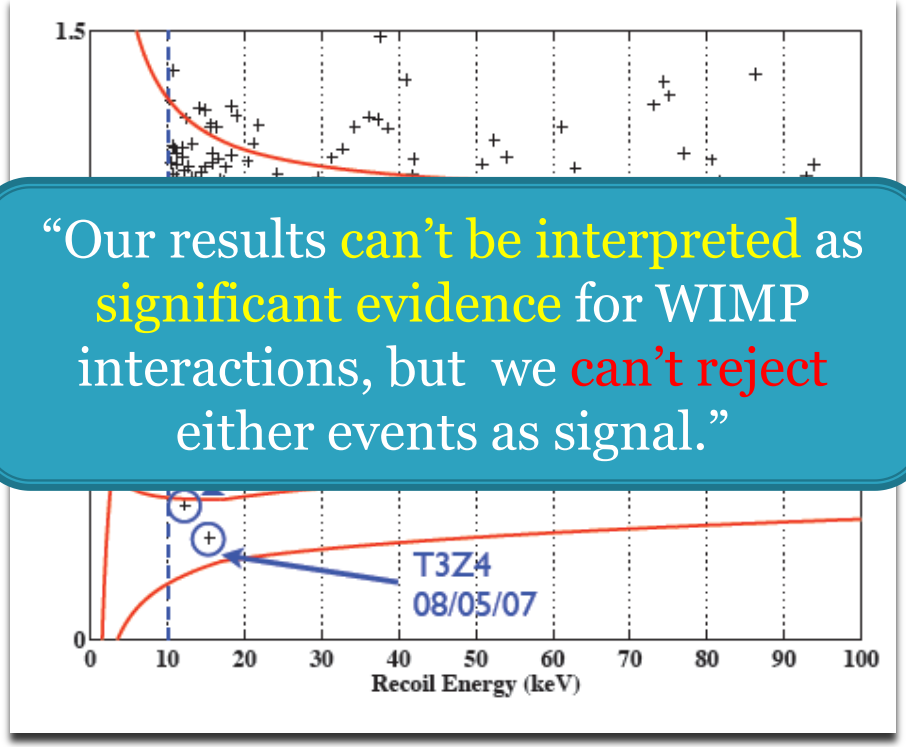
arXiv:1103.4070



CDMS: Directly detected?

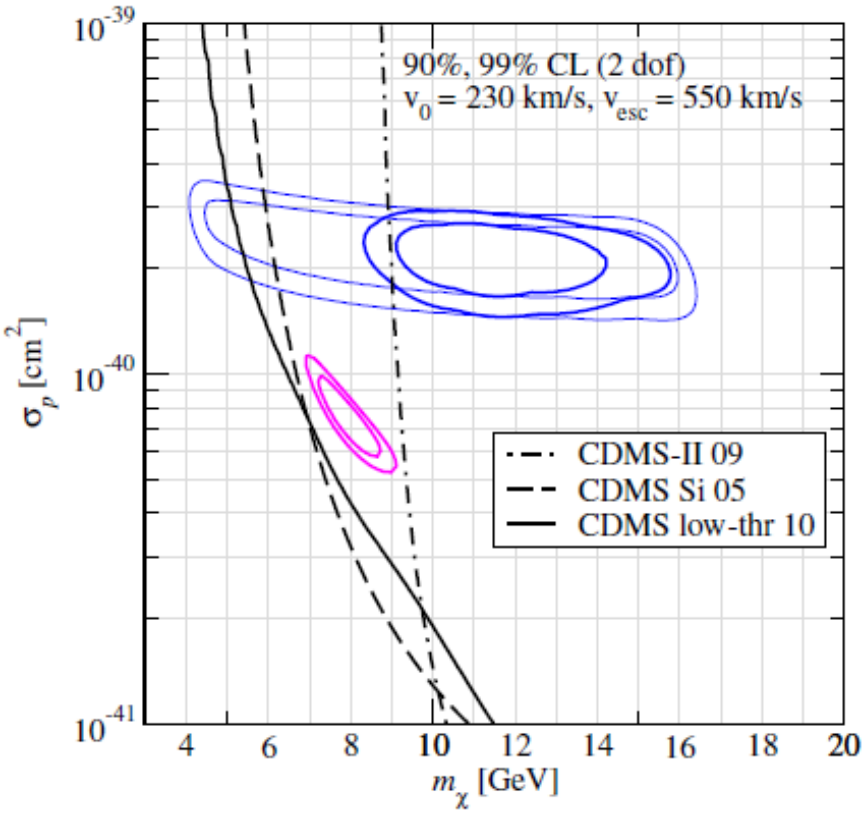
Sience **327**, 1619 (2010)

- Ge target
- **CDMS II** observed two candidate events.
- Background estimation due to surface leakage: 0.8±0.1 (stat)±0.2 (syst)
- The probability that the 2 signals are just surface events is 23%.



"Our results can't be interpreted as significant evidence for WIMP interactions, but we can't reject either events as signal."

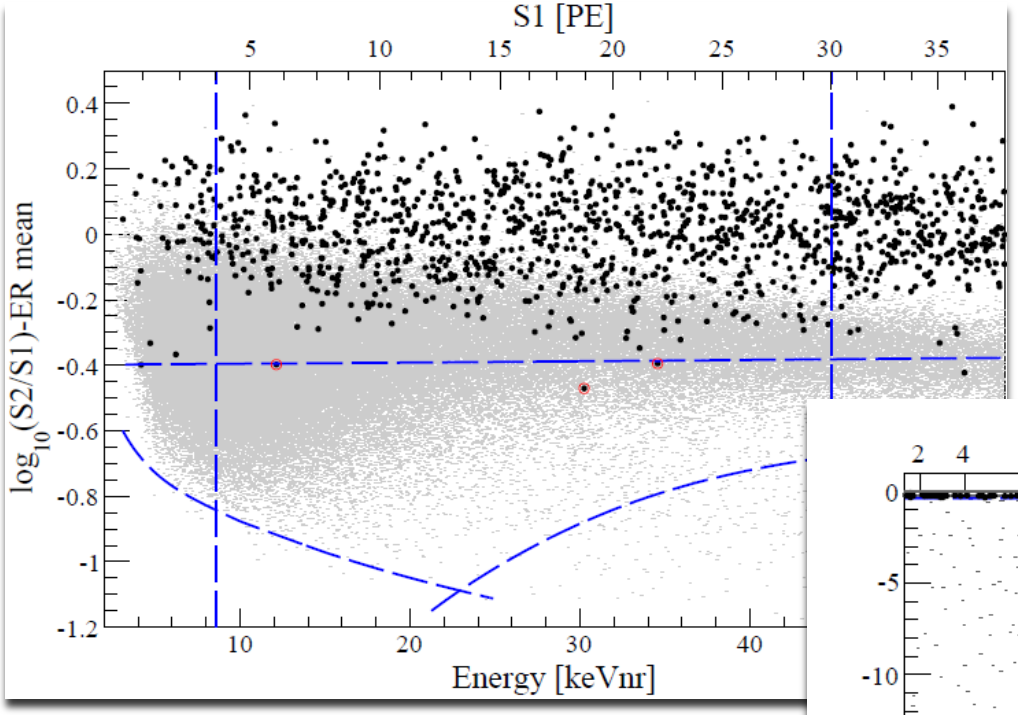
CDMS bounds

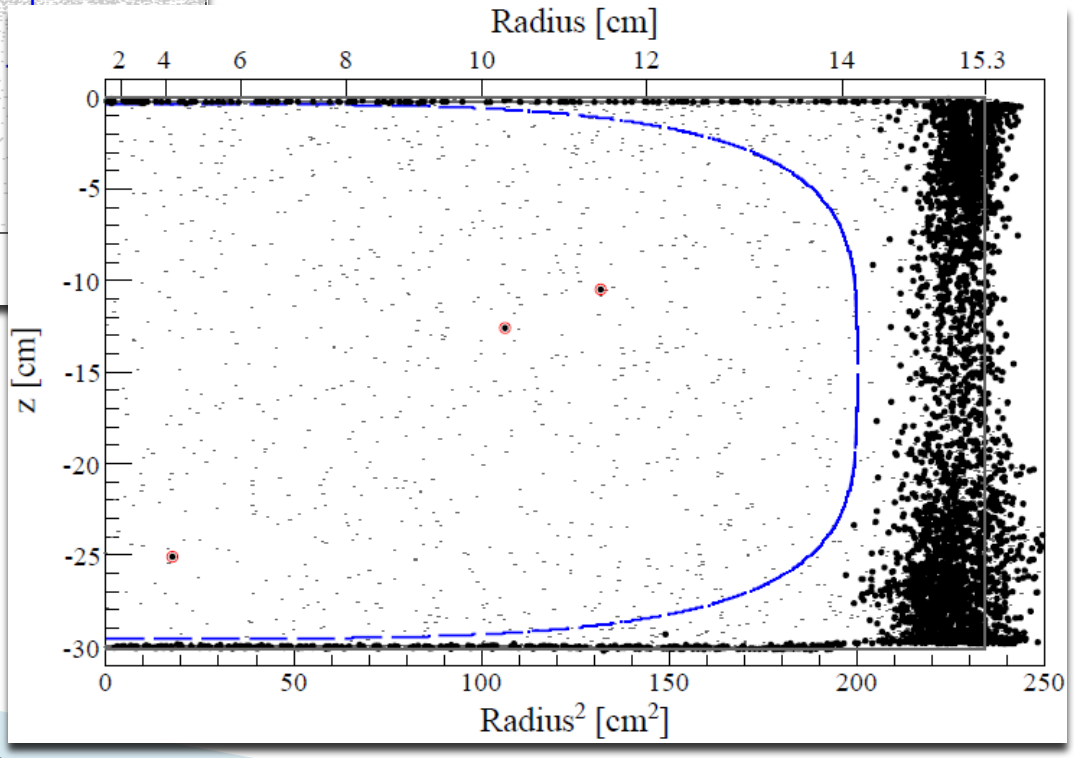


- CDMS data on Si astro-ph/0509259: 12 kg day, 7 keV threshold
- low-threshold analysis of Soudan Ge data (2006–08) 1011.2482
  do not insist on full NR/electr discrimination →
  accept some background →
  lower threshold to 2 keV

XENON100 result

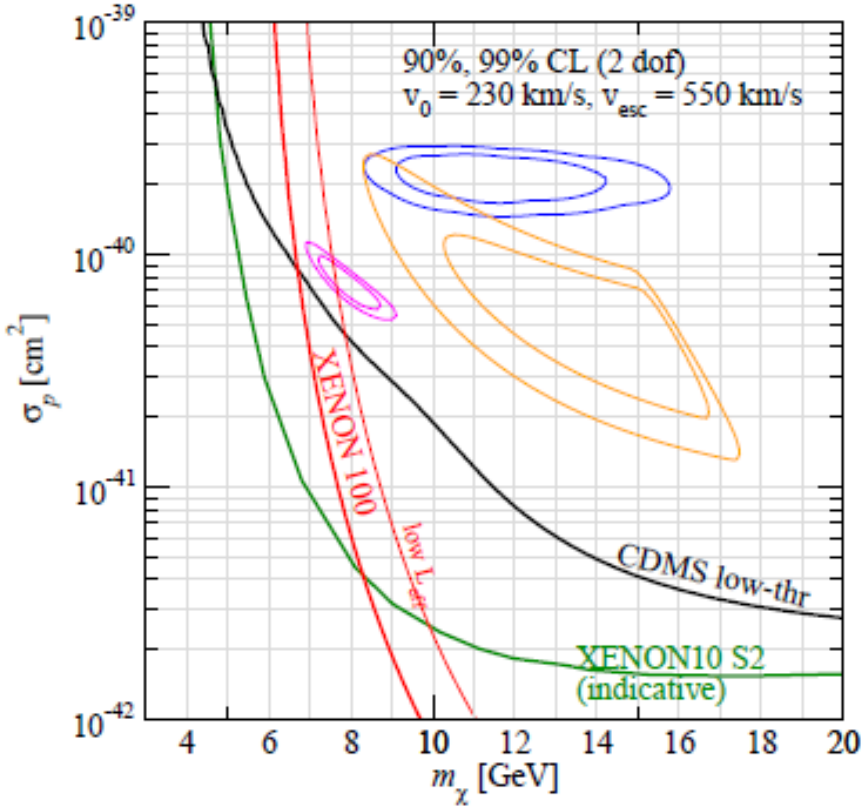
- 3 events, 1.8 ± 0.6 background





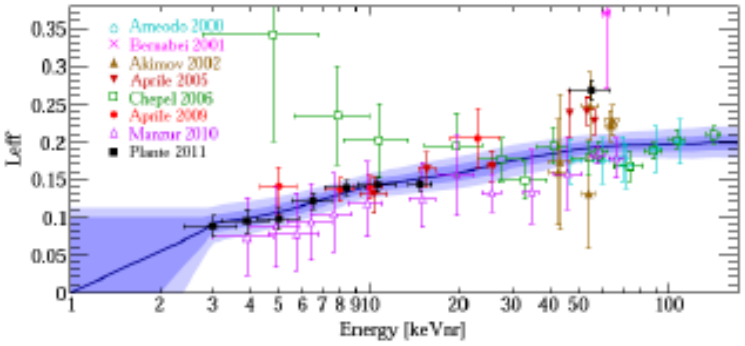
arXiv:1104.2549

XENON100 bounds



translate $S1$ [PE] into E_{nr} [keV]:

$$E_{nr} = \frac{S1}{L_{eff}(E_{nr})} \frac{1}{L_y} \frac{S_e}{S_n}$$



heated discussion: Collar, McKinsey, 1005.0838; XENON100, 1005.2615; Collar, McKinsey, 1005.2615; Savage et al., 1006.0972; Sorensen, 1007.3549; Bezrukov, Kahlhoefer, Lindner, 1011.3990; Collar, 1006.2031, 1106.0653

S2 only analysis of XENON 10 data Sorensen @ iDM 2010; J. Angle et al. 1104.3088

energy scale from ionization signal (S2) $\rightarrow$ independent of L_{eff}

see also Collar, 1010.5187, 1106.0653

How to reconcile?

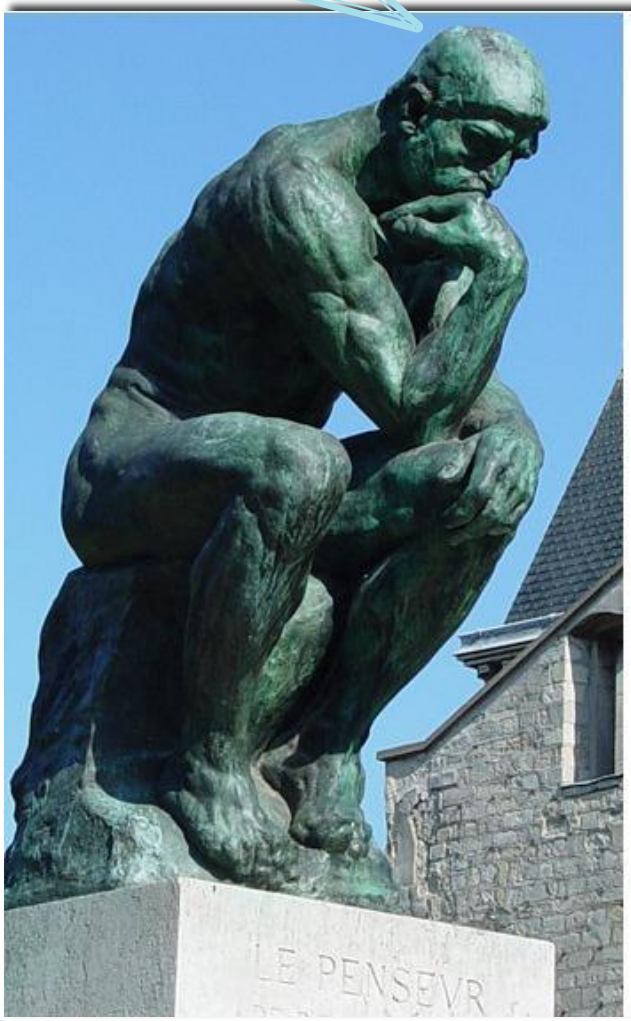
- Experimental issues?
  $\sim$ 10 GeV region is experimentally challenging
  systematic uncertainties on quenching factors, energy scale, threshold effects, backgrounds... have to be understood and taken into account before making strong statements.

However, in order to get a consistent picture we need to assume that

- CDMS made a major calibration error (in Ge and Si),
- the XENON S2 analysis is completely wrong,
- there is a serious problem with L_{eff} in Xenon, and
- major error in the Na quenching factor determination for DAMA

Detected ?

Um… Well…



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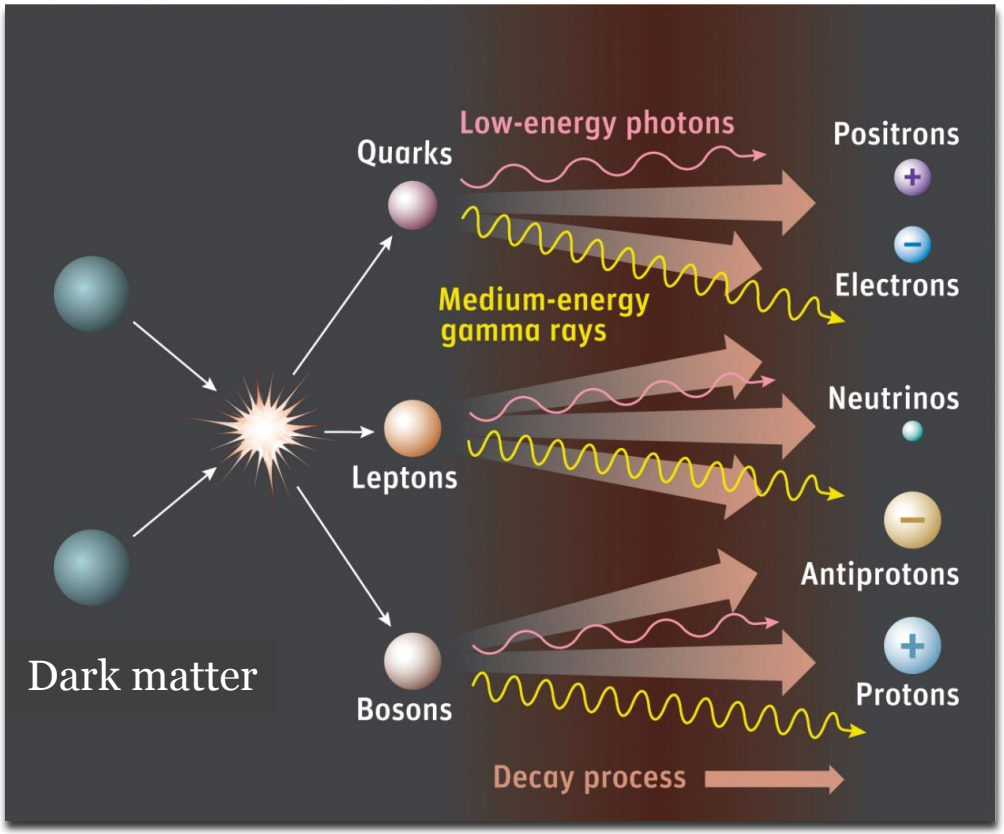
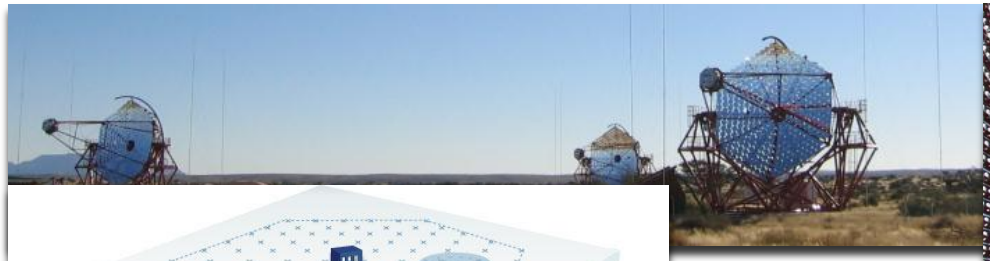
Indirect detection

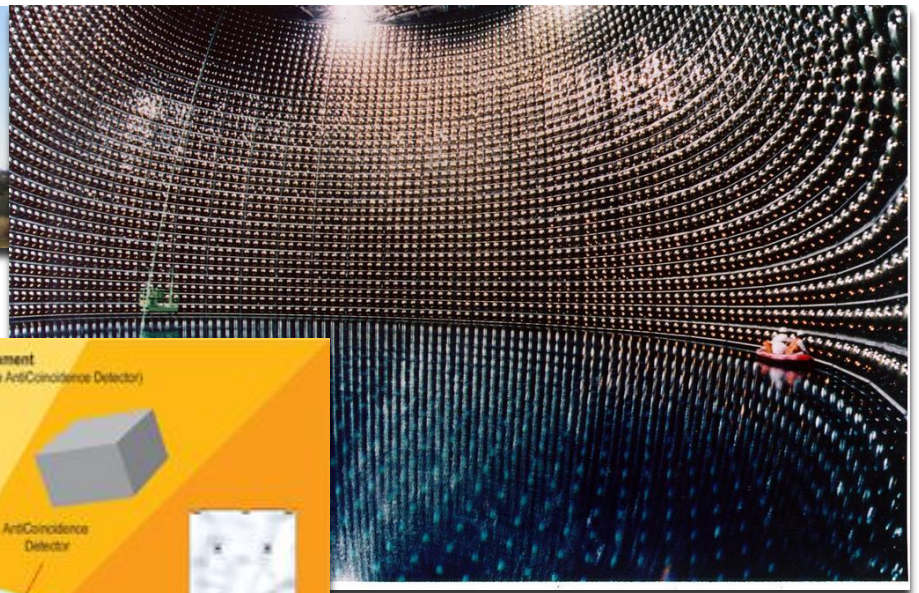
- Indirect detection experiments search for the products of DM annihilation: gamma rays, neutrinos, positrons or antiprotons
- Not conclusive evidence since the backgrounds from other sources are not fully understood.

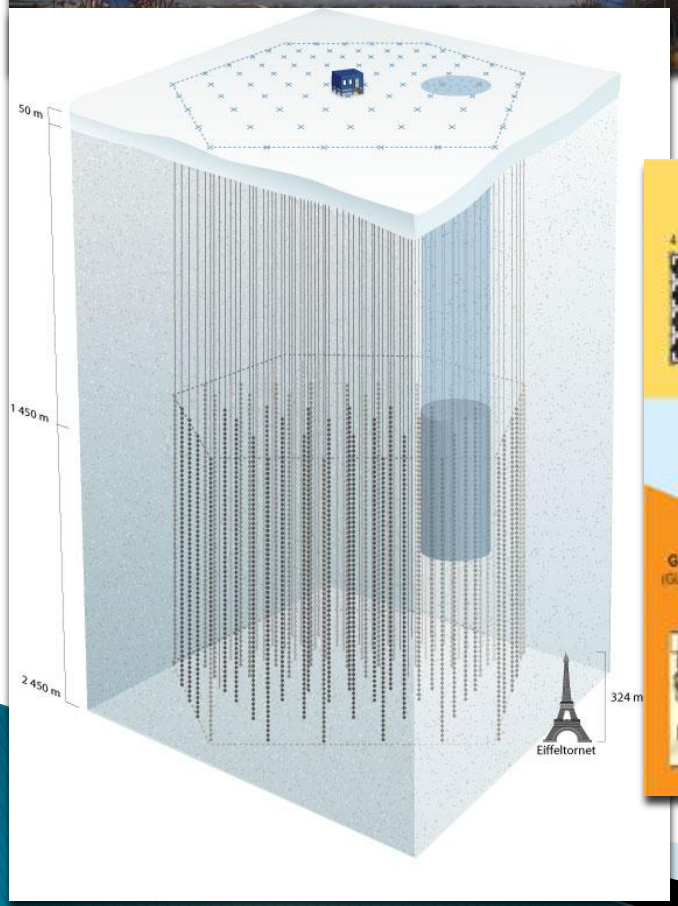


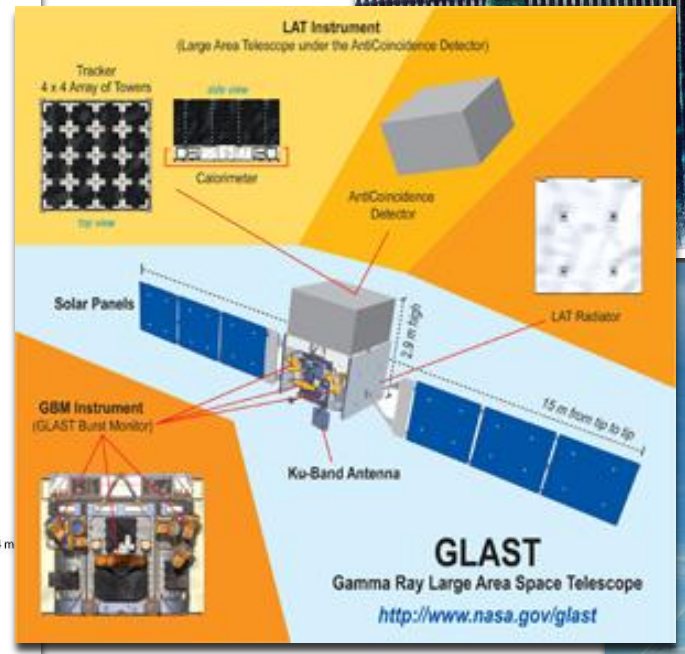
Indirect detection experiments

- SPI/ITRGRAL, HESS, AMANDA, IceCube, ANTARES, Super Kamiokande, PPB-BETS, ATIC, EGRET, HEAT, AMS-01 & 02, PAMELA, Fermi/LAT

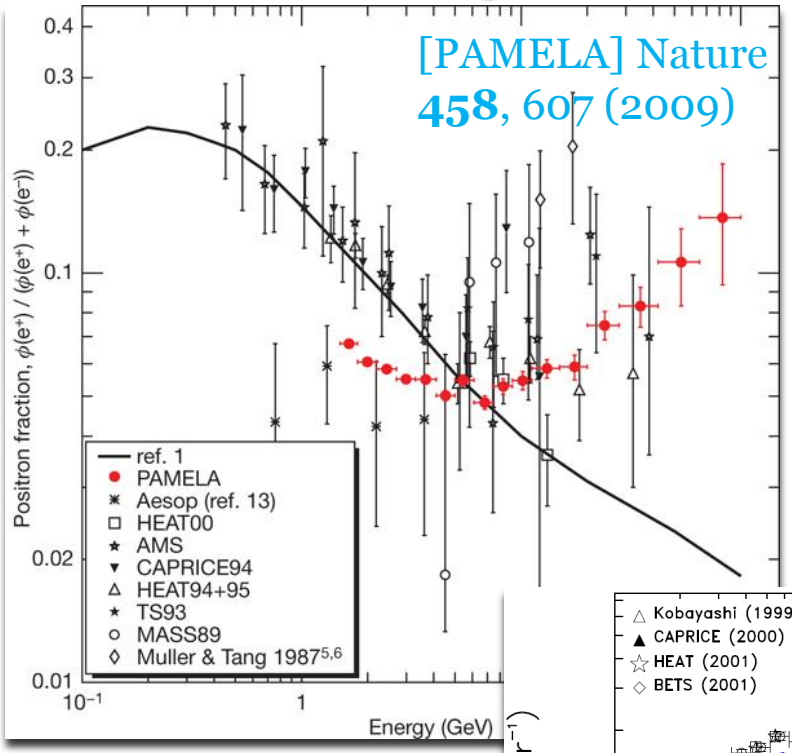


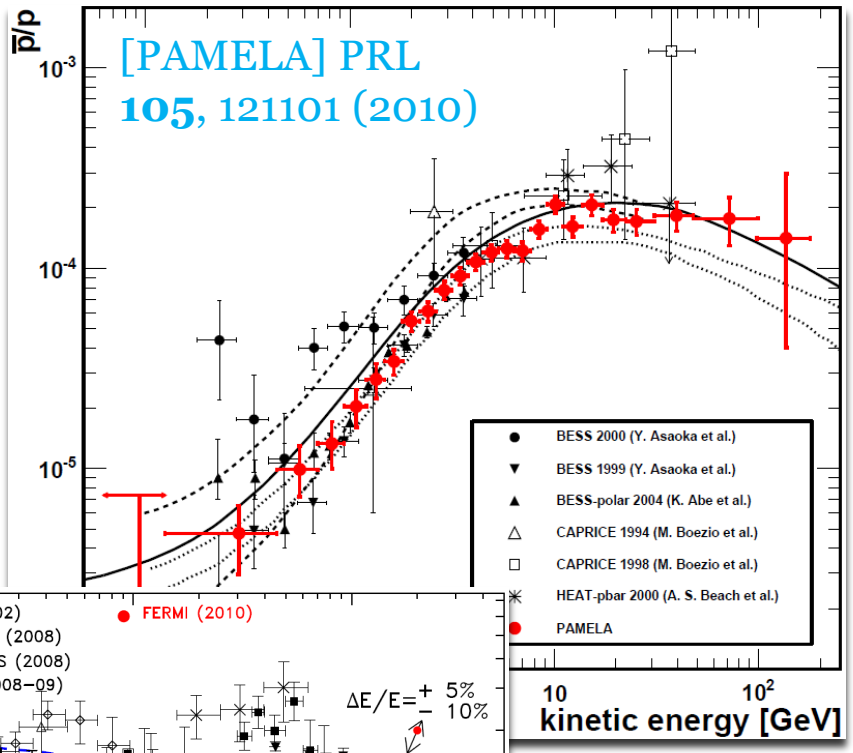


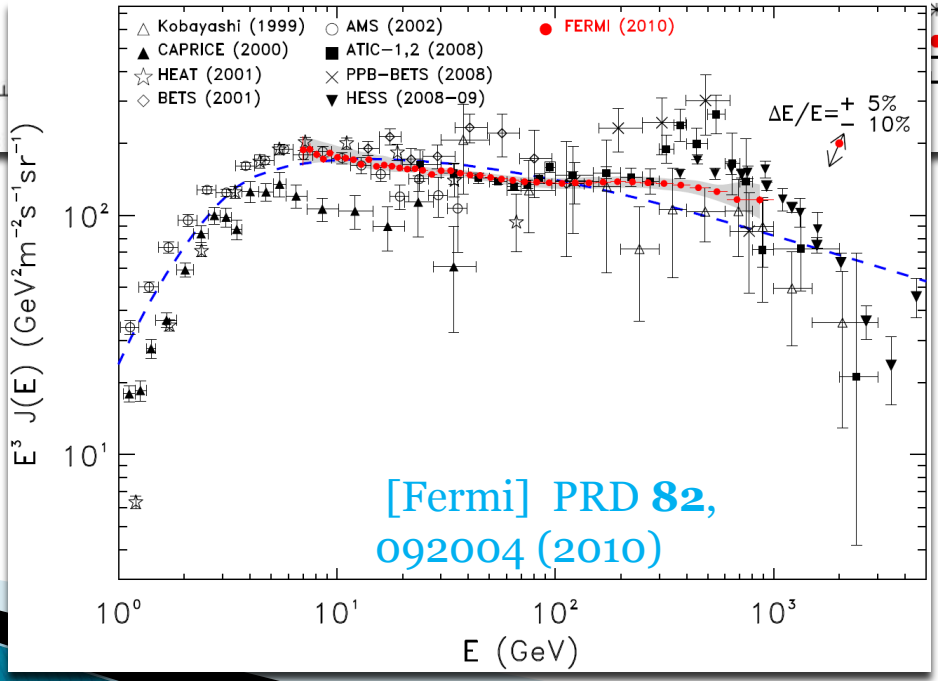




Indirectly detected?







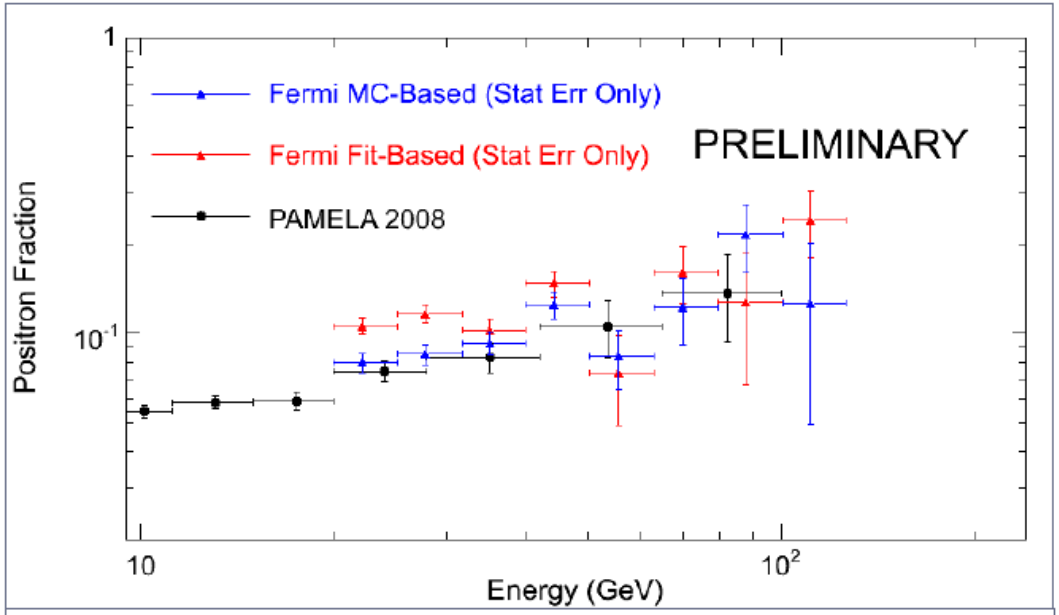
FERMI positron/electron ratio

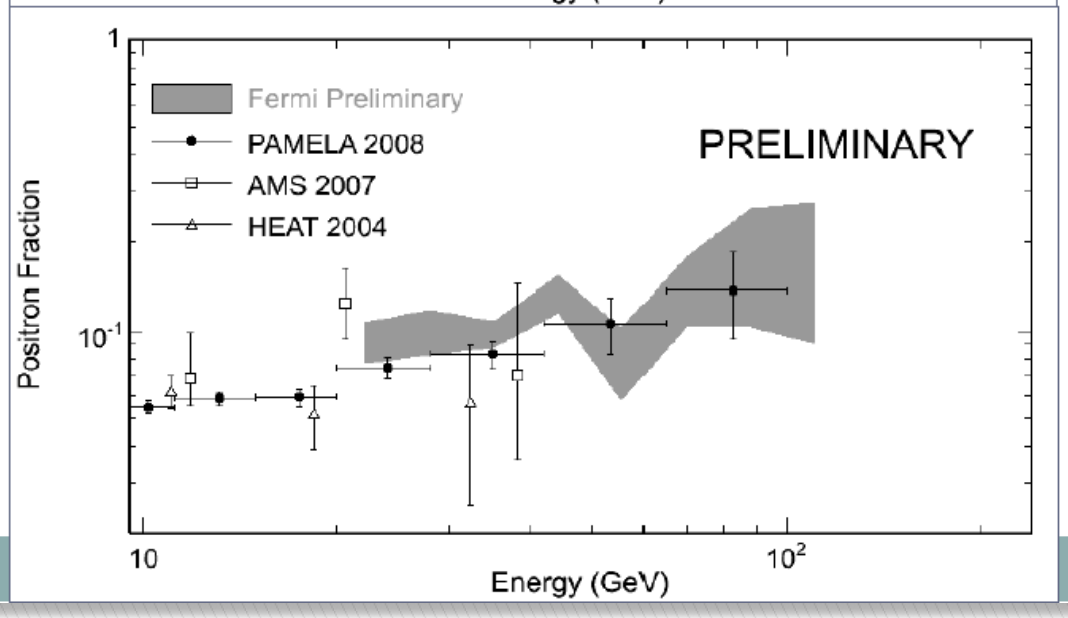
The Fermi-LAT has measured the cosmic-ray positron and electron spectra separately, between 20 – 130 GeV, using the Earth's magnetic field as a charge discriminator

The two independent methods of background subtraction,Fit-Based and MC-Based, produce consistent results

The observed positron fraction is consistent with the one measured by PAMELA

Warit Mitthumsiri et al. @ Fermi Symposium (May 2011)





The origin of excessive energetic e^- & e^+ ?

Candidates of e^- & e^+ source

- Nearby mature pulsars:

  In order to contribute significantly, neither too far, nor young, nor old

  D. Hooper, P. Blasi, P. D. Serpico, JCAP (2009)
  H. Yuksel, M. D. Kistler, T. Stanev, PRL (2009)
  S. Profumo, arXiv:0812.4457

- Supernova remnants

  N. J. Shaviv, E. Nakar, T. Piran, PRL (2009)
  Y. Fujita, K. Kohri, R. Yamazaki, K. Ioka, PRD (2009)

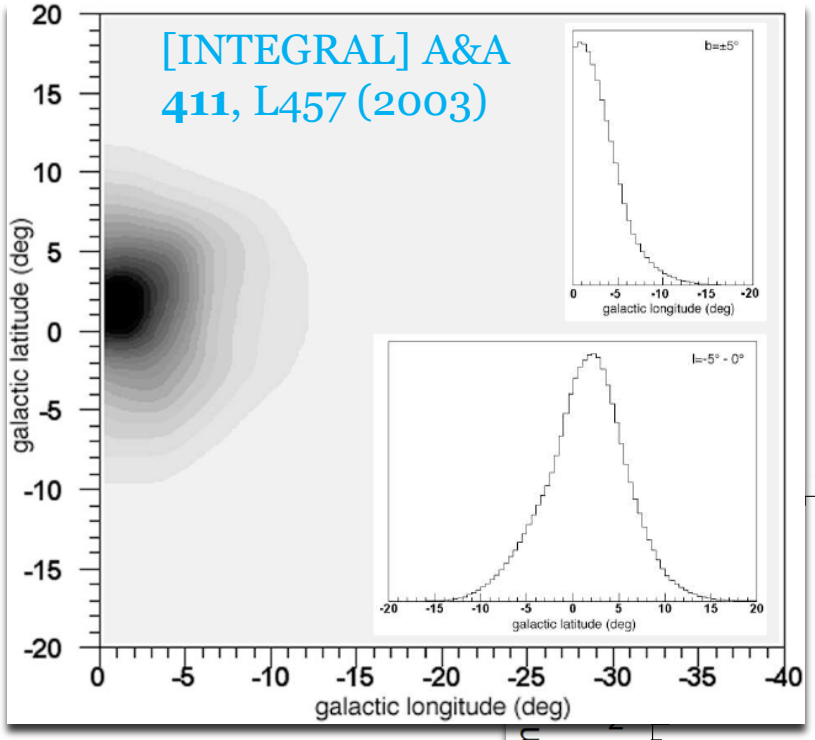
- **TeV** Dark matter: decay or annihilation

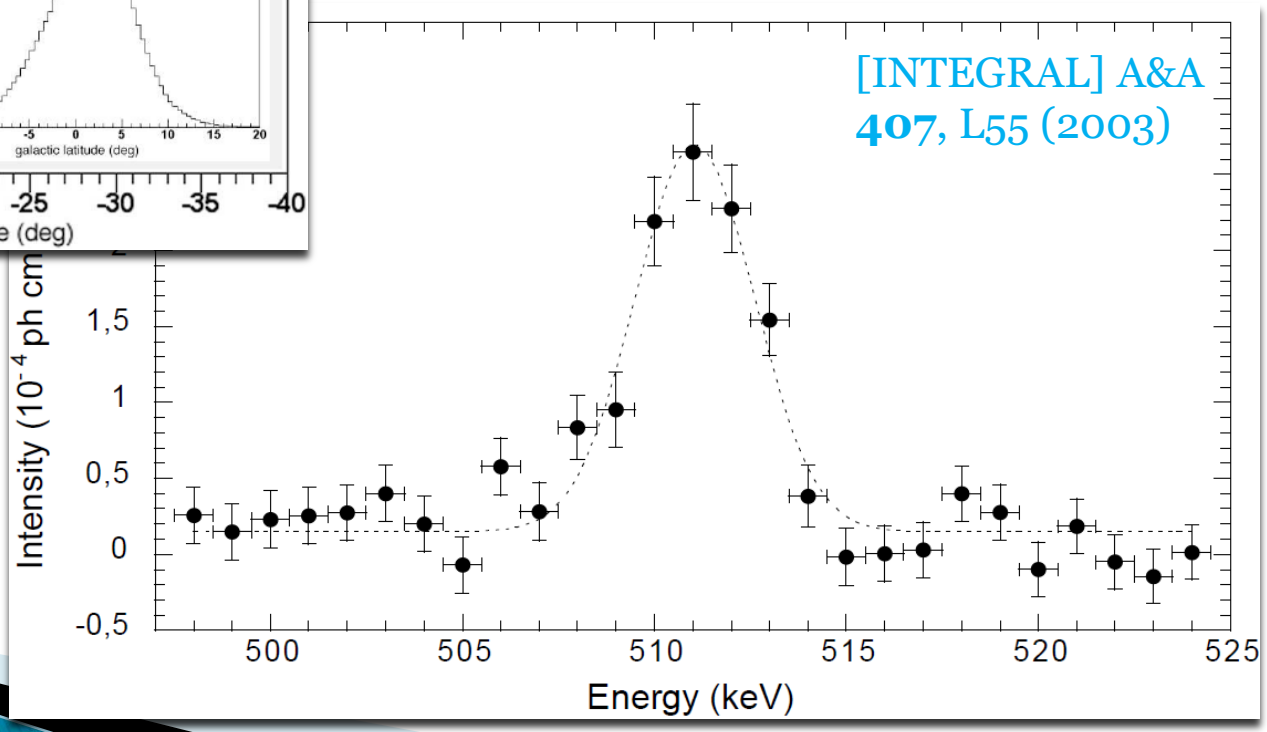
  Excesses in e^- & e^+ but not in $\bar{p}$ ⟶ **Leptophilic DM**

  - ☞ Decay: Required lifetime ~ O(10^{26}s)
  - ☞ Annihilation: Majorana neutralino is disfavored.

    ∵ $\langle\sigma v\rangle_{\chi\chi\to f\bar{f}}$ is suppressed by m_f^2/m_χ^2 due to helicity flip.

511 keV line from GC





Possible sources of e^+

- Astrophysical sources
  Massive stars, Hypernovae, Cosmic-ray interactions ($N + p \longrightarrow \pi^+ \longrightarrow e^+$), X-ray binaries (HMXB, LMXB), Classical novae, Thermonuclear Type Ia supernovae (SN Ia).

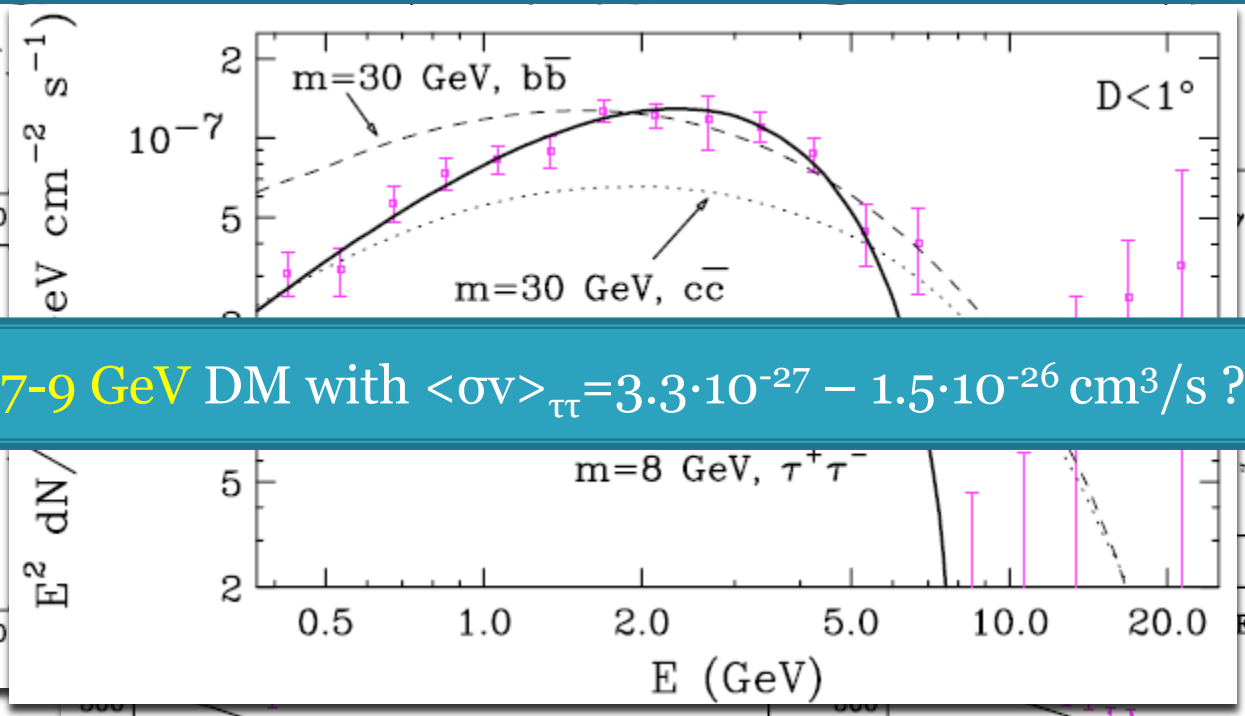
  (Knodlseder et al., Astron. Astrophys. **441**, 513 (2005))

- Particle physics
  - ⋆ Light dark matter (DM) annihilation or decay
    $\longrightarrow$ Axino, Sterile neutrino, Light scalar, N=2 SUSY.
  - ⋆ Others $\longrightarrow$ Exciting heavy DM with near-degenerate sates.
- The shape of the emission region and the majority of the emission impose severe constrains on the principal galactic positron sources.
- SN Ia and LMXB may satisfy these constraints, but there still exist uncertainties in the knowledge about the spatial distribution of these objects and the positron escape processes.
- Light (MeV) DM annihilation or decay in the galactic bulge is an interesting idea.

DM annihilation in GC?

Hooper & Goodenough,
PLB **697**, 412(2011)

Additional spherically symmetric component $\propto r^{-2\gamma}$
with $\gamma=1.34\pm0.04$



7-9 GeV DM with $\langle\sigma v\rangle_{\tau\tau}=3.3\cdot10^{-27}-1.5\cdot10^{-26}$ cm^3/s ?

Pulsar interpretation:
K.N.Abazajian,
JCAP **1103**, 010 (2011)

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Conclusion

- DM direct detection:
  - ✓ DAMA, CoGeNT, CRESST → GeV ?
  - ✓ XENON, CDMS → not detected ?

- DM indirect detection:
  - ✓ PAMELA, Fermi e^- & e^+ → TeV ?
  - ✓ Fermi GC γ-rays → GeV ?
  - ✓ Integral 511 keV line → MeV ?


Thank you