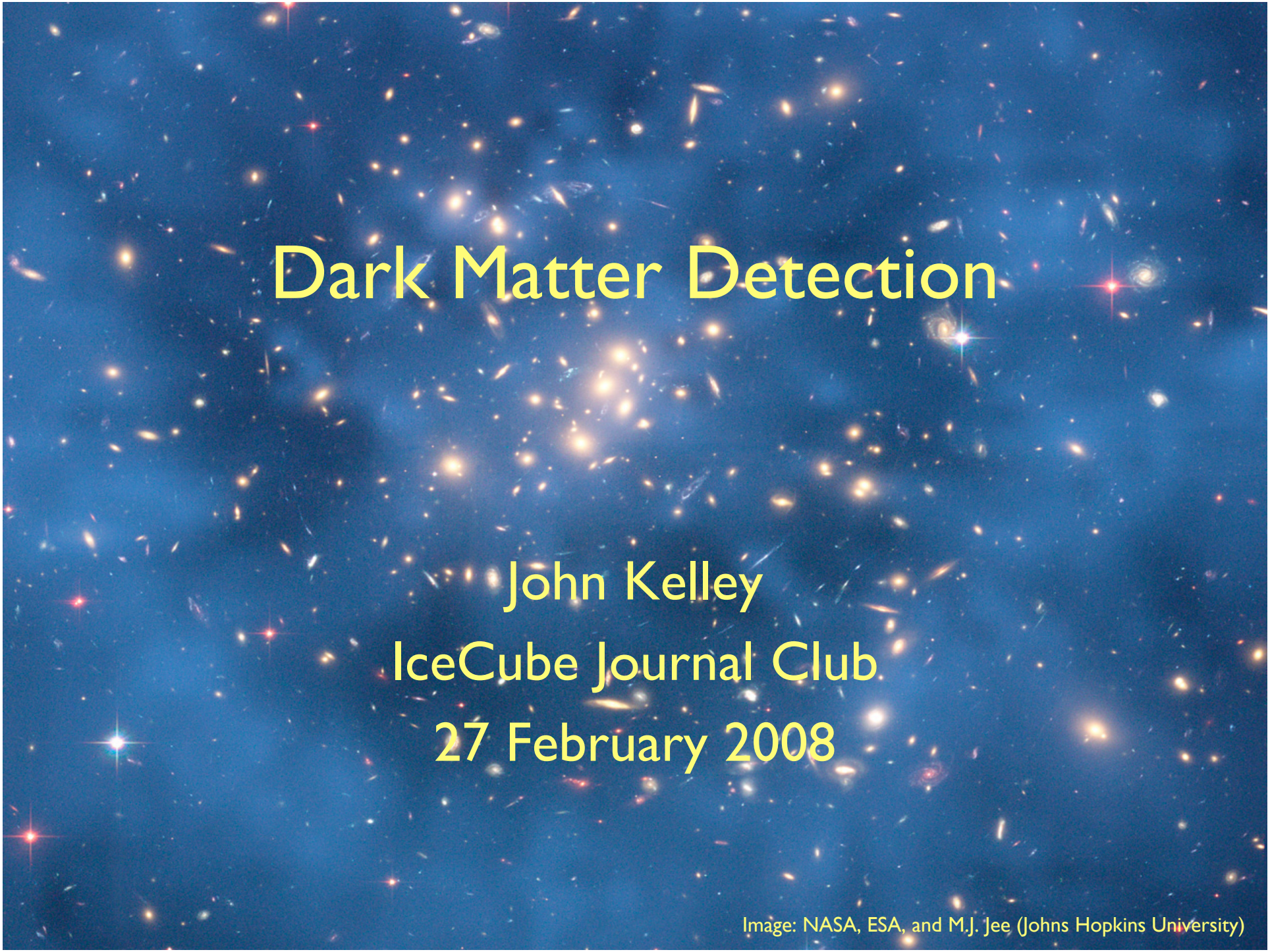

# Dark Matter Detection

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IceCube Journal Club

27 February 2008

Image: NASA, ESA, and M.J. Jee (Johns Hopkins University)

# What is dark matter?

- Experimental evidence is pretty overwhelming
  - galaxy rotation, lensing, structure formation, CMB, etc.
- "Coincidence" between weak scale interactions and necessary relic abundance suggests WIMPs
- Calculating rates in detectors requires a specific model

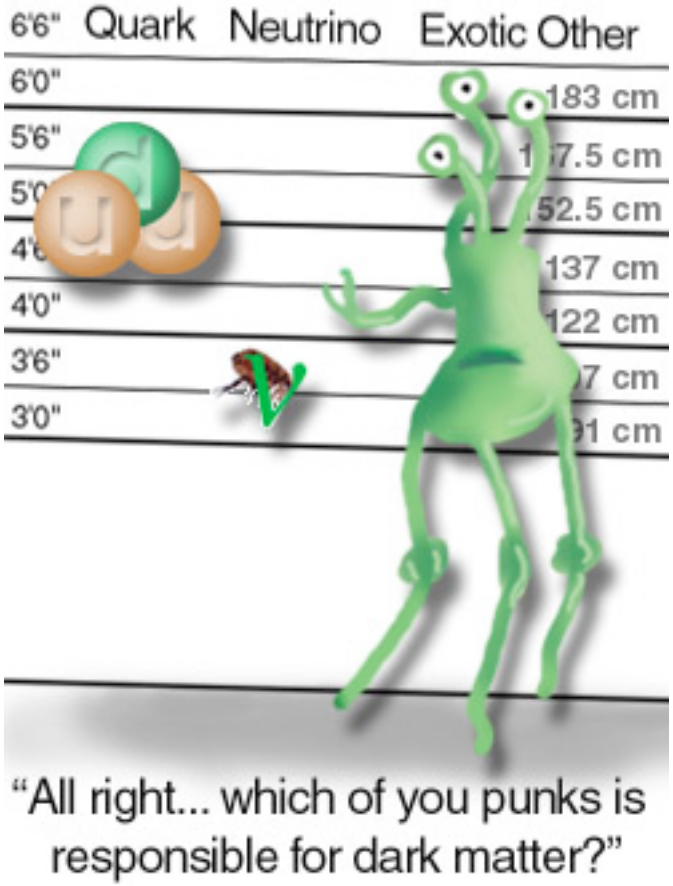



image: PDG (Particle Adventure)

# Supersymmetry

- Well-motivated extension to SM, adds superpartners (fermion ↔ boson)
- Add in *R-parity* (adds B, L conservation back in), you get a stable LSP
- Minimal model ("MSSM") still gives you plenty to work with (63 new parameters)

Graphic: *Symmetry* (Fermilab / SLAC)

| Normal particles | | SUSY partners | |
|---|---|---|---|
| Symbol | Name | Symbol | Name |
| $q = u, c, t$ | up quarks | $\tilde{q}_u^1, ..., \tilde{q}_u^6$ | up squarks |
| $q = d, s, b$ | down quarks | $\tilde{q}_d^1, ..., \tilde{q}_d^6$ | down squarks |
| $l = e, \mu, \tau$ | leptons | $\tilde{l}_1, ..., \tilde{l}_6$ | sleptons |
| $\nu$ | neutrinos | $\tilde{\nu}_1, ..., \tilde{\nu}_3$ | sneutrinos |
| $g$ | gluons | $\tilde{g}$ | gluinos |
| $W^\pm$ | $W$ boson | $\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$ | charginos |
| $H^\pm$ | charged Higgs | | |
| $\gamma$ | photon | | |
| $Z^0$ | $Z$ boson | | |
| $h^0$ $(H_2^0)$ | light scalar Higgs | $\tilde{\chi}_1^0, ..., \tilde{\chi}_4^0$ | neutralinos |
| $H^0$ $(H_1^0)$ | heavy scalar Higgs | | |
| $A^0$ $(H_3^0, P_0)$ | pseudoscalar Higgs | | |

LSP candidate: mixture of photino, zino, (or bino, wino* — "gaugino") and higgsino

* "recall" SM Higgs mechanism: photon and Z from mixing of $W^3$ and B fields

from *Supersymmetric Dark Matter,* Jungman, Kamionkowski, and Greist, *Phys. Rep.* **267**

http://t8web.lanl.gov/people/jungman/susyreview/susyreview.ps.gz

# LSP neutralino cross-sections

- Two cross sections important: annihilation, elastic scattering with nuclei

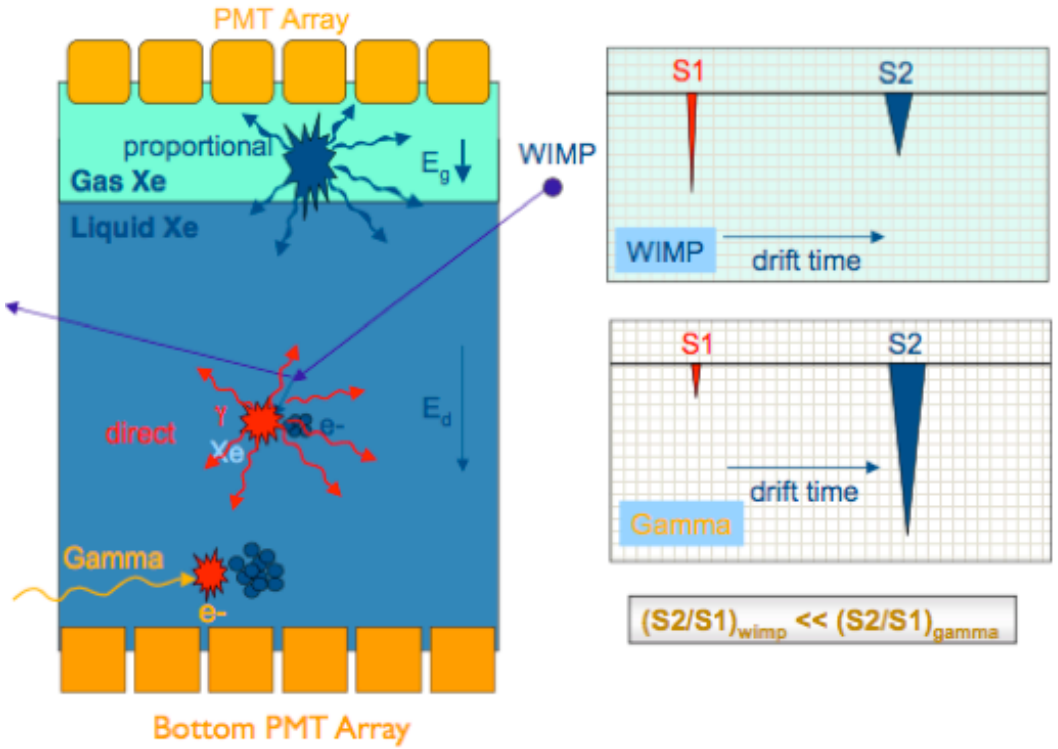
- Components of cross sections depend on gaugino / higgsino composition (among other things) and also on target

| $\sigma_{SD}$ | $\sigma_{SI}$ |
|---|---|
| • spin-dependent (nucleon spin / WIMP spin) | • spin-independent |
| • axial vector interaction ($\gamma_\mu\gamma_5$) | • scalar interaction |
| • Z exchange, squark exchange | • Higgs exchange, squark exchange, loops with gluons |
| • Can be larger for higgsino-like | • Can be larger for gaugino-like (wino, bino) |
| • Can be larger for light nuclei | • Almost always larger for heavy nuclei |

# AAAAH!

Point to remember: cross sections are very model dependent, and different ones are important for different experiments

# Direct DM searches with xenon



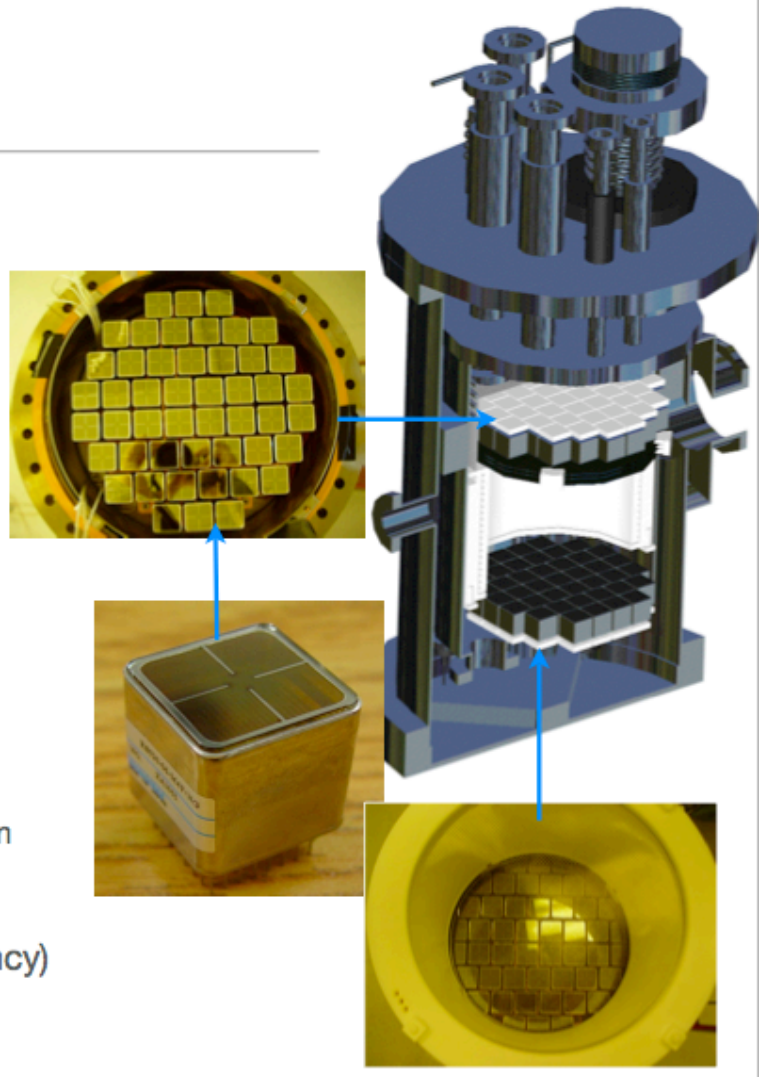

event-by-event discrimination (>99.5%) against dominant background (γ,e,α) by:

- Simultaneous Detection of scintillation (S1) and ionization (S2)
- 3D Event Localization

E. Aprile: http://xenon.astro.columbia.edu/talks/APS2007/aprile-aps_2007.pdf

# The XENON10 Detector

- **22 kg of liquid xenon**
  - ➡ 15 kg active volume
  - ➡ 20 cm diameter, 15 cm drift
- **Hamamatsu R8520 1"×3.5 cm PMTs**
  bialkali-photocathode Rb-Cs-Sb,
  Quartz window; ok at -100°C and 5 bar
  Quantum efficiency > 20% @ 178 nm
- **48 PMTs top, 41 PMTs bottom array**
  - ➡ x-y position from PMT hit pattern; $\sigma_{x\text{-}y} \approx$ 1 mm
  - ➡ z-position from $\Delta t_{drift}$ ($v_{d,e^-} \approx$ 2mm/μs), $\sigma_Z \approx$0.3 mm
- **Cooling: Pulse Tube Refrigerator (PTR),**
  90W, coupled via cold finger ($LN_2$ for emergency)

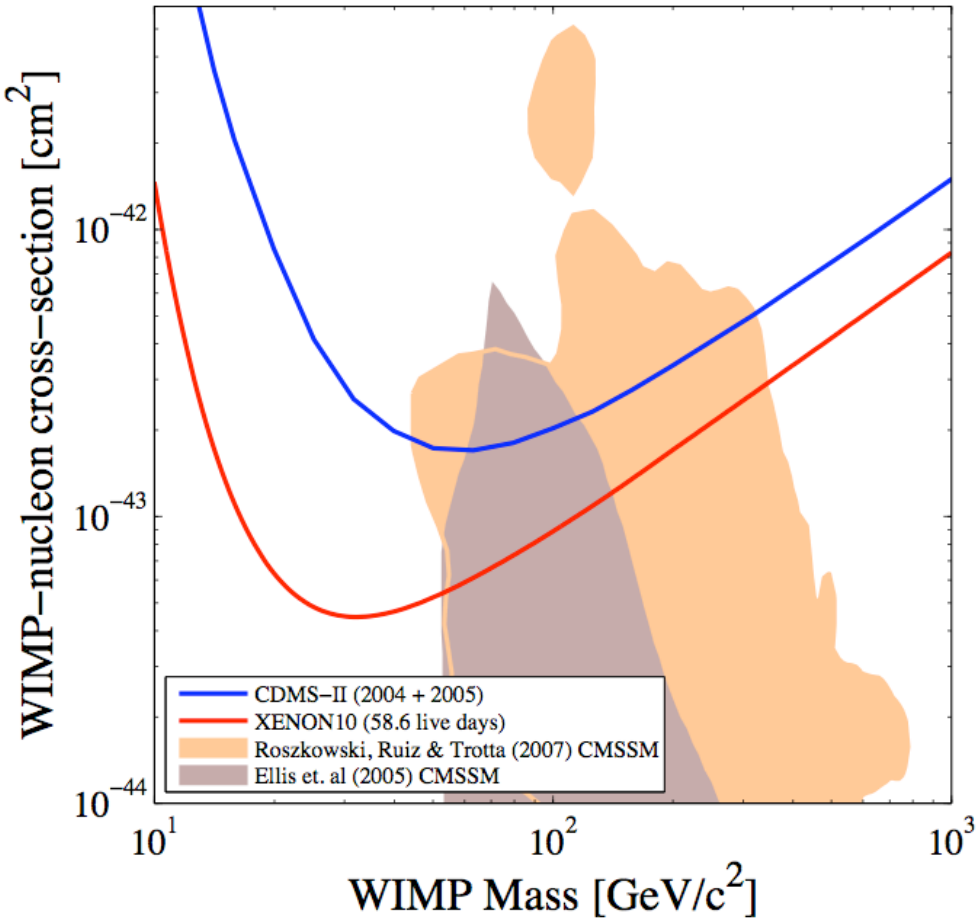


R. Gaitskell: http://gaitskell.brown.edu/physics/talks/0703_C2CR07/070228_DM_Noble_Gaitskell_v02.pdf

# First Results

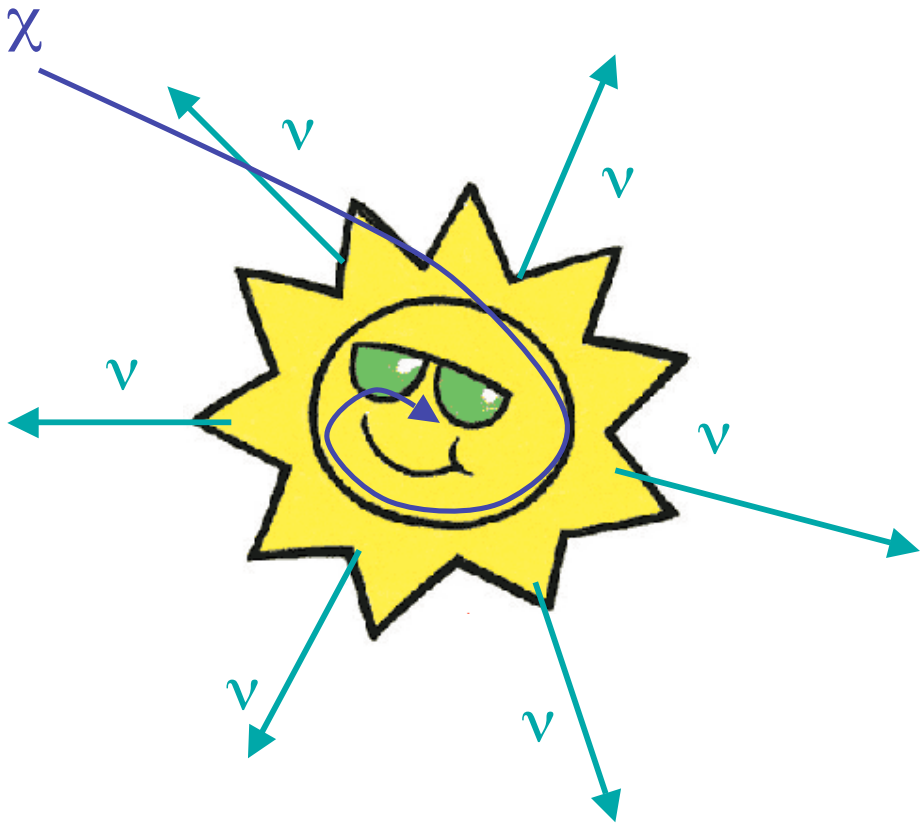
http://arxiv.org/abs/0706.0039

- 58.6 days of livetime
- This analysis: spin-independent cross-section (but SD analysis via odd isotopes forthcoming)
- Best existing SI limits
- Plan: 10 modules by 2009



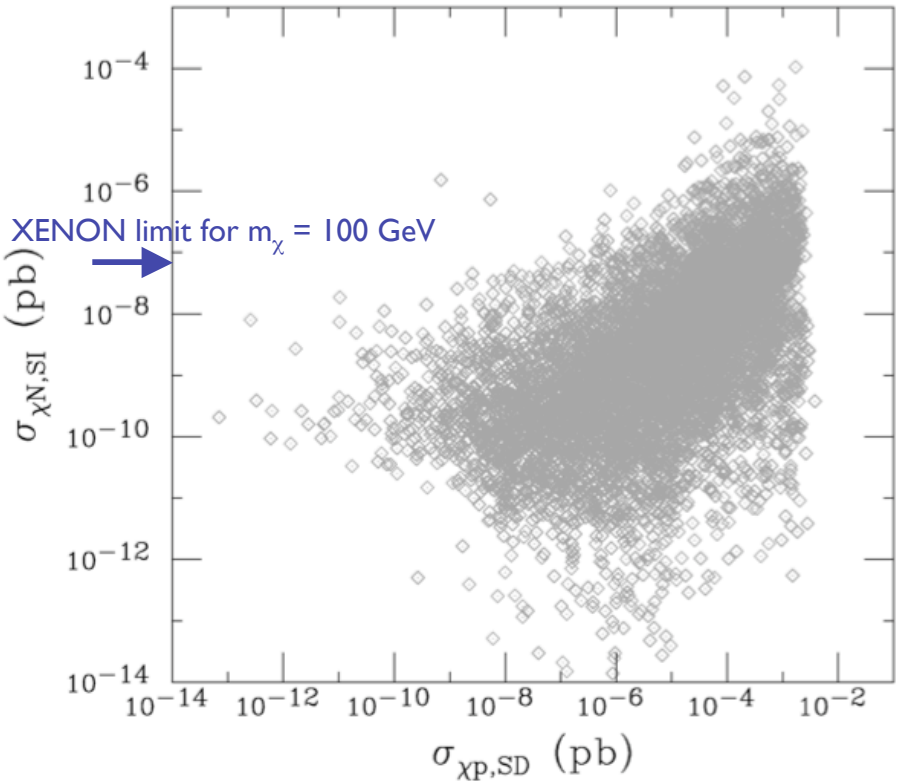
# DM detection in IceCube

- Basic idea: Sun captures DM (depends on ES cross section with H & He, historical density of DM, etc.)
- DM annihilates in sun (another cross section) to $b\bar{b}$, $W^+W^-$, ZZ, $\tau^+\tau^-$, etc.
- Produces $\nu$ of E ~ 1/3-1/2 $m_\chi$ ~ O(100 GeV)



# Halzen & Hooper calculations

http://arxiv.org/abs/hep-ph/0510048




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

- Idea: $\sigma_{SI}$ is being probed to small values by direct-detection experiments
- But there are a wide range of models with small $\sigma_{SI}$ and large $\sigma_{SD}$
- This means:
  - an IceCube signal is not ruled out
  - IceCube searches are complementary

# The Math of Annihilation

Capture rate (WIMPs gained / sec):

$$C^{\odot} \simeq 3.35 \times 10^{20}\,\mathrm{s}^{-1} \left(\frac{\rho_{\mathrm{local}}}{0.3\,\mathrm{GeV/cm}^3}\right) \left(\frac{270\,\mathrm{km/s}}{\bar{v}_{\mathrm{local}}}\right)^3 \left(\frac{\sigma_{\mathrm{H,SD}} + \sigma_{\mathrm{H,SI}} + 0.07\,\sigma_{\mathrm{He,SI}}}{10^{-6}\,\mathrm{pb}}\right) \left(\frac{100\,\mathrm{GeV}}{m_{\mathrm{WIMP}}}\right)^2 \quad (1)$$

Annihilation rate (WIMPs lost / sec):

$$A^{\odot} N^2 \qquad A^{\odot} = \frac{\langle \sigma v \rangle}{V_{\mathrm{eff}}}$$

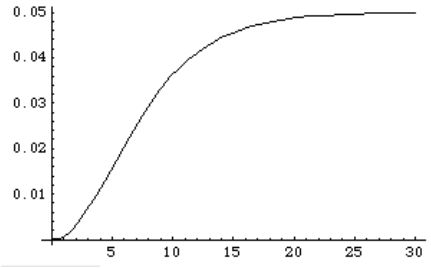
DE for N(t):

$$\dot{N} = C^{\odot} - A^{\odot} N^2$$

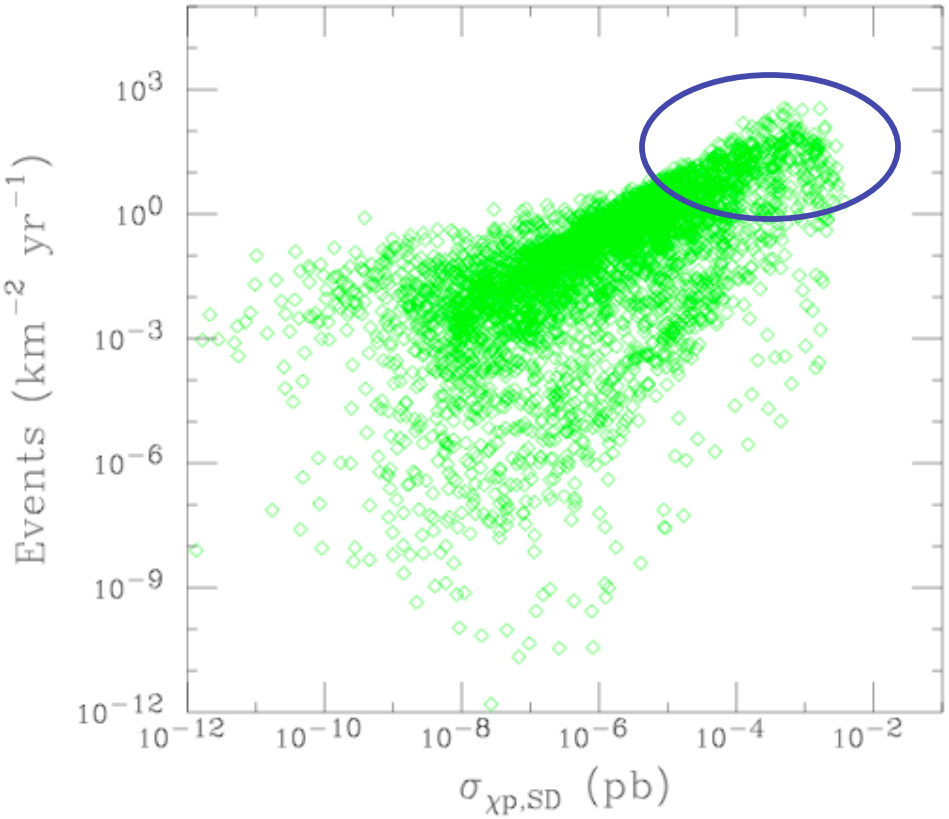
solution for $N_0 = 0$ is N(t) = sqrt(C/A) tanh(sqrt(CA) t)

Annihilation rate now (*annihilations* / sec):

$$\Gamma = \frac{1}{2} A^{\odot} N^2 = \frac{1}{2} C^{\odot} \tanh^2\left(\sqrt{C^{\odot} A^{\odot}}\, t_{\odot}\right)$$



# Neutralino $\nu_\mu$ Event Rates



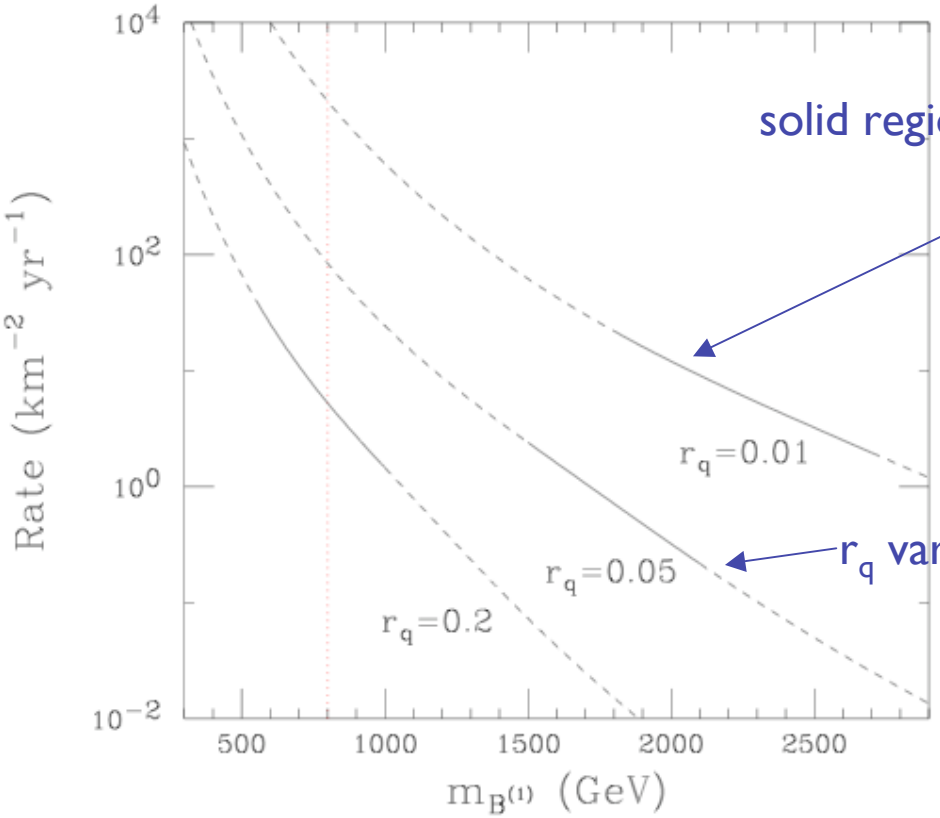

- All models evade 2005 CDMS bound by 100x (so also evade XENON10 bound)
- Interesting models: higgsino fraction > 1%
- NB: muon threshold assumed of 50 GeV (deep core extension will help!)

# Other Possibilities

- SUSY dark matter not the only possibility

- Universal Extra Dimensions model
  - extra compact dimensions
  - SM particles + momenta in the extra dimensions: "tower" of KK partners
  - existence of a stable lightest KK particle (LKP); could be DM
  - could have large $\sigma_{p,SD}$ but small $\sigma_{N,SI}$

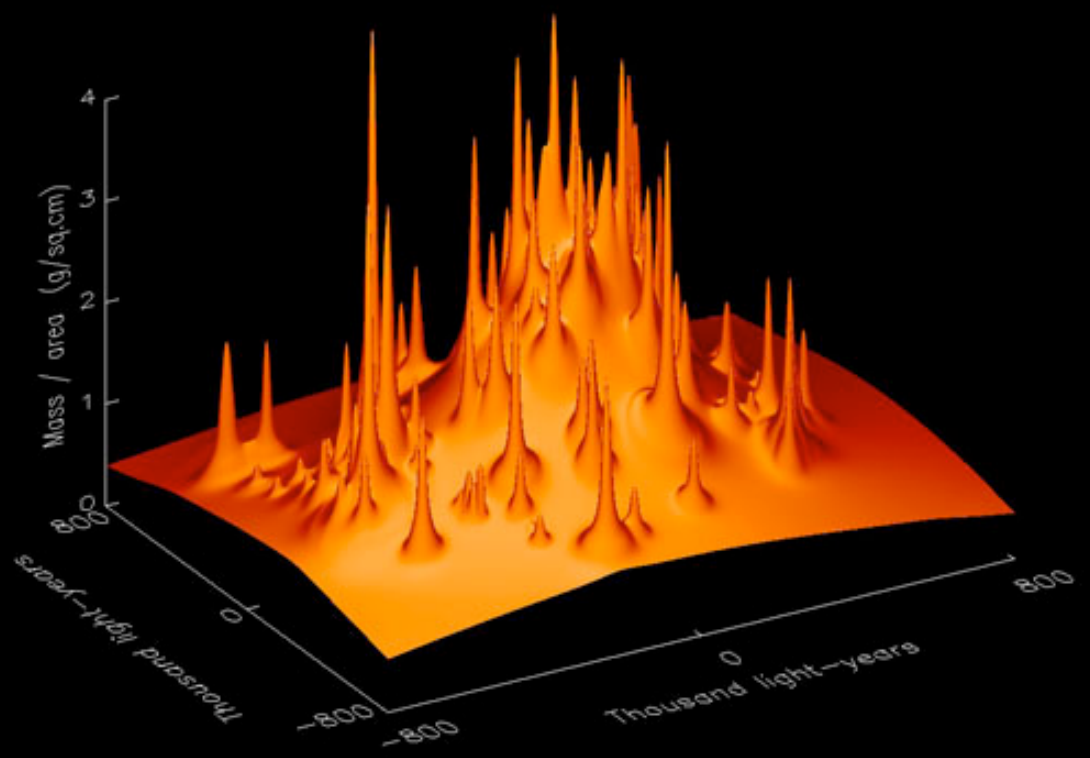
# IceCube Event Rates




solid regions: good relic density

$r_q$ varies for different KK models

# The End




CL00024 mass distribution, lsst.org