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Detection of a subdominant DM component

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KITP - August 2002

Direct detection: G. Duda, G. Gelmini (UCLA); P. Gondolo (CWRU)
Phys. Lett. B 529, 187 (2002) [hep-ph/0102200]

Indirect detection: G. Duda, G. Gelmini (UCLA); P. Gondolo (CWRU)
J. Edsjö (Stockholm) and J. Silk (Oxford).
[in preparation]

Assume WIMP's constitute only a small fraction of the total DM, ARE THEY DETECTABLE?

Assume we find a DM signal, HAVE WE FOUND THE DOMINANT DM COMPONENT?

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ITP - 8/02 L2

Motivation:

THEORETICAL ASPECTS OF DARK MATTER DETECTION

Jun 2001

...the supersymmetric dark matter parameter space.

In this contribution, we will discuss the current status of the expected neutralino-proton elastic cross sections in the MSSM and CMSSM. These results will be applied to the possibility of direct dark matter detection.

As noted earlier, we will restrict our attention to regions of parameter space for which the relic density of neutralinos is of cosmological interest. For an age of the Universe $t > 12$ Gyr, there is a firm upper bound on the relic density $\Omega_\chi h^2 < 0.3$, where Ω_χ is the fraction of critical density in the form of neutralinos, χ, and h is the Hubble parameter in units of 100 km/s/Mpc. This limit represents a strict cosmological bound on the supersymmetric parameter space. We also focus our discussion on the parameter values which lead to relic densities with $\Omega_\chi h^2 > 0.1$. While this does not place any bound on supersymmetry, it is a reasonable requirement for dark matter candidates. Neutralinos with a lower density could not be the dominant form of dark matter in our Galaxy, and therefore detection rates would necessarily be suppressed.

2. The MSSM vs. The CMSSM

As discussed here by John Ellis, the neutralino LSP is the lowest-mass eigenstate combination of the Bino $\tilde{B}$, Wino $\tilde{W}$ and Higgsinos $\tilde{H}_{1,2}$, whose mass matrix N is diagonalized by a matrix Z: $diag(m_{\chi_{1,...,4}}) = Z^* N Z^{-1}$. The composition of the lightest neutralino may be written as

$$\chi = Z_{\chi 1}\tilde{B} + Z_{\chi 2}\tilde{W} + Z_{\chi 3}\tilde{H}_1 + Z_{\chi 4}\tilde{H}_2$$

We assume universality at the ...
as well as ...

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Direct Detection: "Compensation argument"

$$\text{Rate} \sim \rho_{\text{WIMP local}}\ \sigma_{\text{scatt}} \sim \Omega_{\text{WIMPs}}\ \sigma_{\text{scatt.}} \sim \frac{\sigma_{\text{scatt.}}}{\sigma_{\text{annih.}}} \sim \text{const.}$$

- $f = \dfrac{\rho_{\text{WIMP-local}}}{\rho_{\text{CDM-local}}} = \left(\dfrac{\Omega_{\text{WIMP's}}}{\Omega_{\text{CDM}}}\right)_{\text{UNIVERSE}}$
- $\Omega_{\text{WIMPS}} \sim \dfrac{1}{(\sigma_{\text{annih.}})_{\text{Early Universe}}}$
- In many instances crossing arguments hold: if $\sigma_{\text{annih}}\uparrow$, also $\sigma_{\text{scatt}}\uparrow$ so $\dfrac{\sigma_{\text{scatt.}}}{\sigma_{\text{annih.}}} \sim \text{const.}$

(Arguments already known since the inception of subject!)

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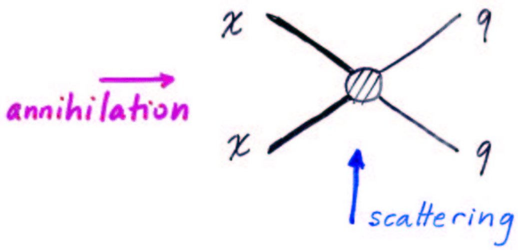
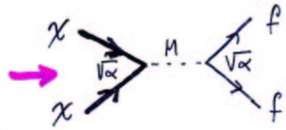
CROSSING SYMMETRY

relates reduced amplitudes of crossed channels



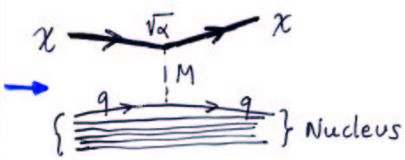
$$A_a = A_s$$

However: ≠ channel may dominate, there are form factors, resonances - - -



$$\sigma_a \simeq N_a\, m_\chi^2\, |A_a|^2$$

N_a # of annih. channels, $|A_a|^2 \simeq \dfrac{\alpha^2}{M^4}$



$$\sigma_s \simeq \frac{m_\chi^2\, m_N^2}{(m_\chi + m_N)^2}\, |A_s|^2$$

$$|A_s|^2 \simeq A^2 \frac{\alpha^2}{M^4}$$

Form factor; A: atomic #

for m_χ, A const:

$$\boxed{\frac{\sigma_s}{\sigma_a} \simeq \frac{\alpha^2/M^4}{\alpha^2/M^4} \simeq \text{const}}$$

Imperfect argument, but still holds sometimes...

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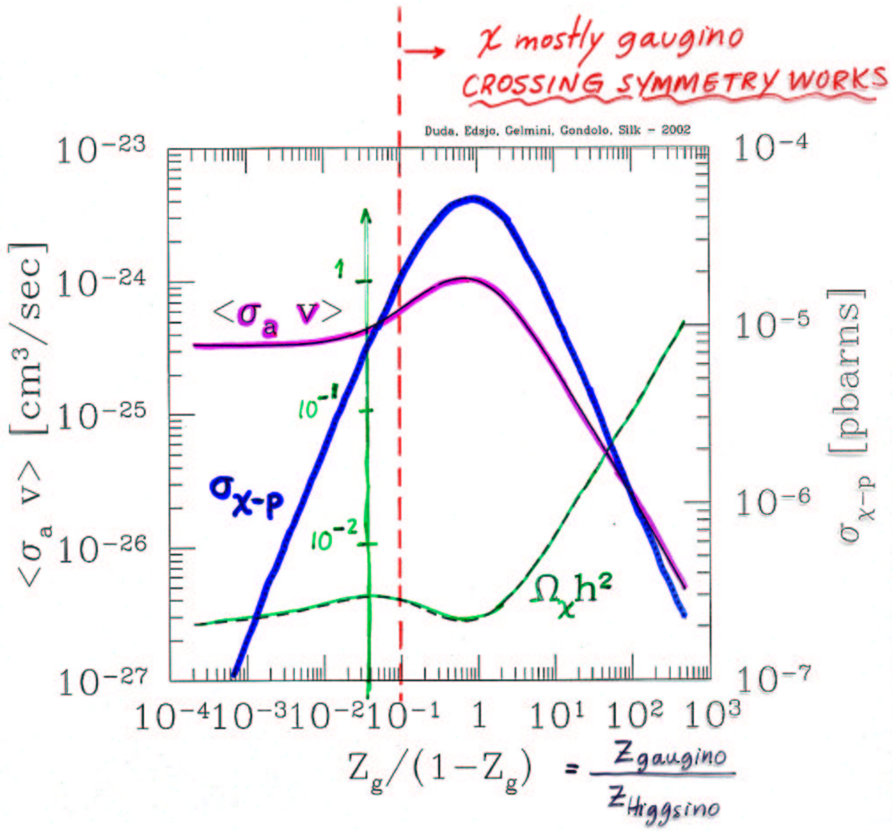
EXAMPLE: keep m_χ and other SUSY parametes constant, change only compositions



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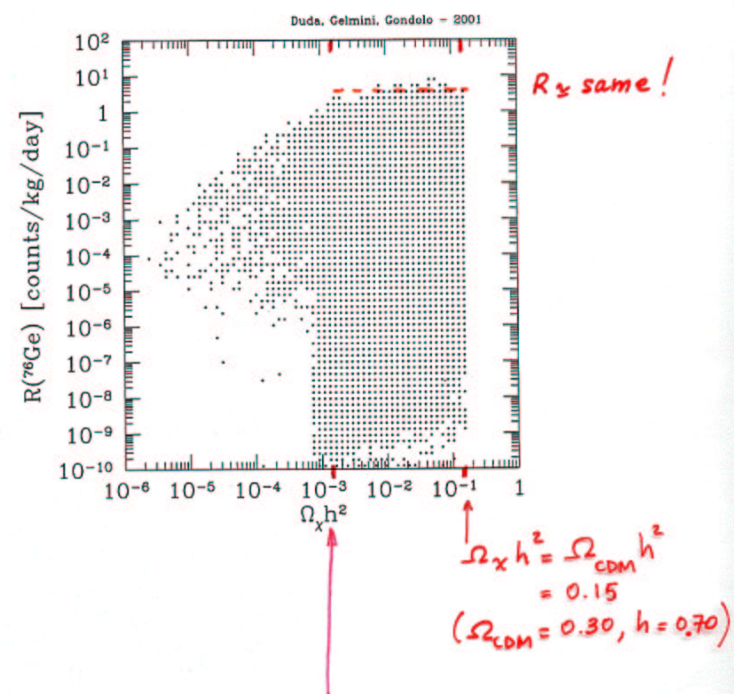
Using table of models solved with "DARKSUSY", about 45,000. points => area of models (regular grid)

"DARKSUSY" code: Gondolo, Edsjö, Bergström, Ullio, Baltz astro-ph/0012234



R changes within factor of 3 to $\Omega_\chi = 10^{-2}\Omega_{CDM}$!

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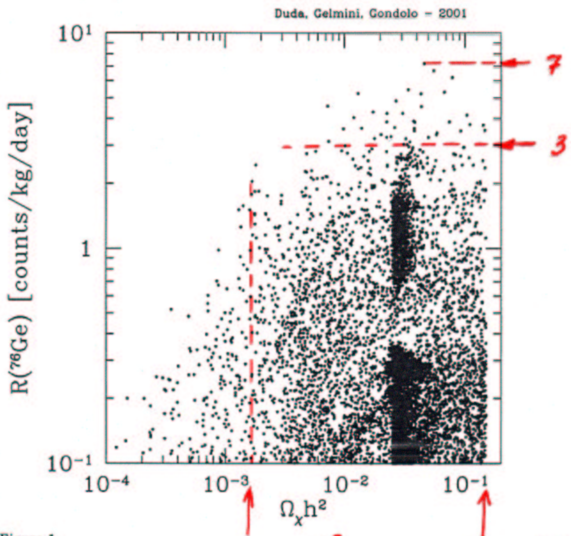
Detail of highest rates (actual points in parameter space shown, density is meaningless)



$\Omega_\chi = 10^{-2}\Omega_{CDM}$ $\Omega_\chi = \Omega_{CDM}$

R changes within a factor of 3 to $\Omega_\chi = 10^{-2}\Omega_{CDM}$

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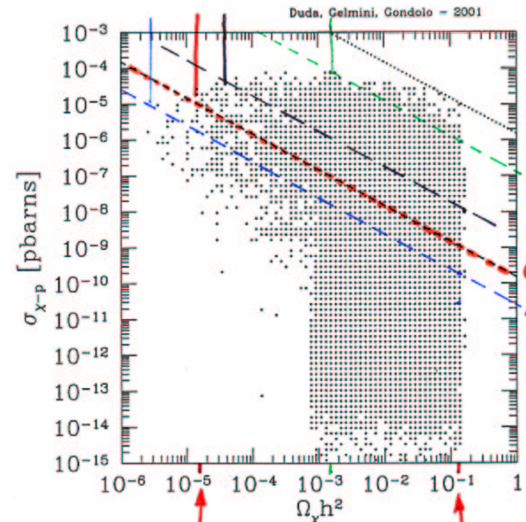
DIRECT DETECTION: HOW FAR WE COULD GO?

Use $\sigma_{\chi-p}$, the scattering neutralino-proton cross section (statement independent of nucleous used)



$\Omega_\chi = 10^{-4}\Omega_{CDM}$ $(\Omega_\chi h^2 = 1.5\ 10^{-5})$

$\Omega_\chi = \Omega_{CDM} = 0.3$ $(\Omega_\chi h^2 = 0.15)$

We could detect even neutralinos composing $\rho_\chi \simeq 10^{-5} \rho_{halo}$!

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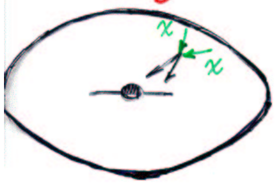
Indirect Detection: "Compensation arguments"

• **In the galactic halo:** the annihilation rate Γ_A is



$$\Gamma_A \sim \rho_\chi^2 \sigma_a \sim \rho_\chi \sim \Omega_\chi$$

$$\rho_\chi \sigma_a \sim \Omega_\chi \sigma_a \sim \frac{\sigma_a}{\sigma_{a\,E.U.}} \sim \text{const}$$

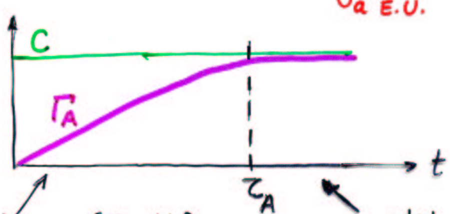
Rate decreases with $\Omega_\chi \downarrow$

• **Inside the Earth or Sun:**

Capture rate from dark halo: C

$$C \sim \rho_\chi \sigma_{scatt} \sim \text{const}$$

$$\rho_\chi \sigma_s \sim \Omega_\chi \sigma_s \sim \frac{\sigma_s}{\sigma_{a\,E.U.}} \sim \text{const.}$$



non-equilibrium (Earth)

$$\Gamma_A \sim \sigma_a N_\chi^2 \sim \sigma_a C^2 \sim \sigma_a \sim \frac{1}{\Omega_\chi}$$

equilibrium (Sun)

$$\Gamma_A \simeq C \sim \text{const}$$

Rate keeps constant or increases with $\Omega_\chi \downarrow$

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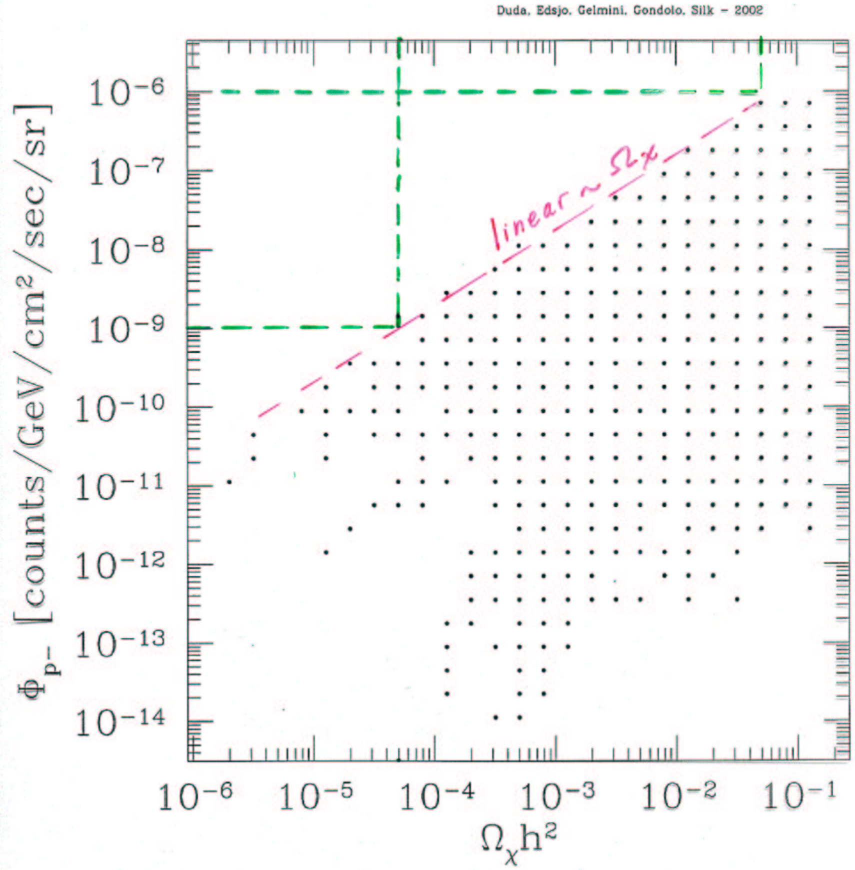
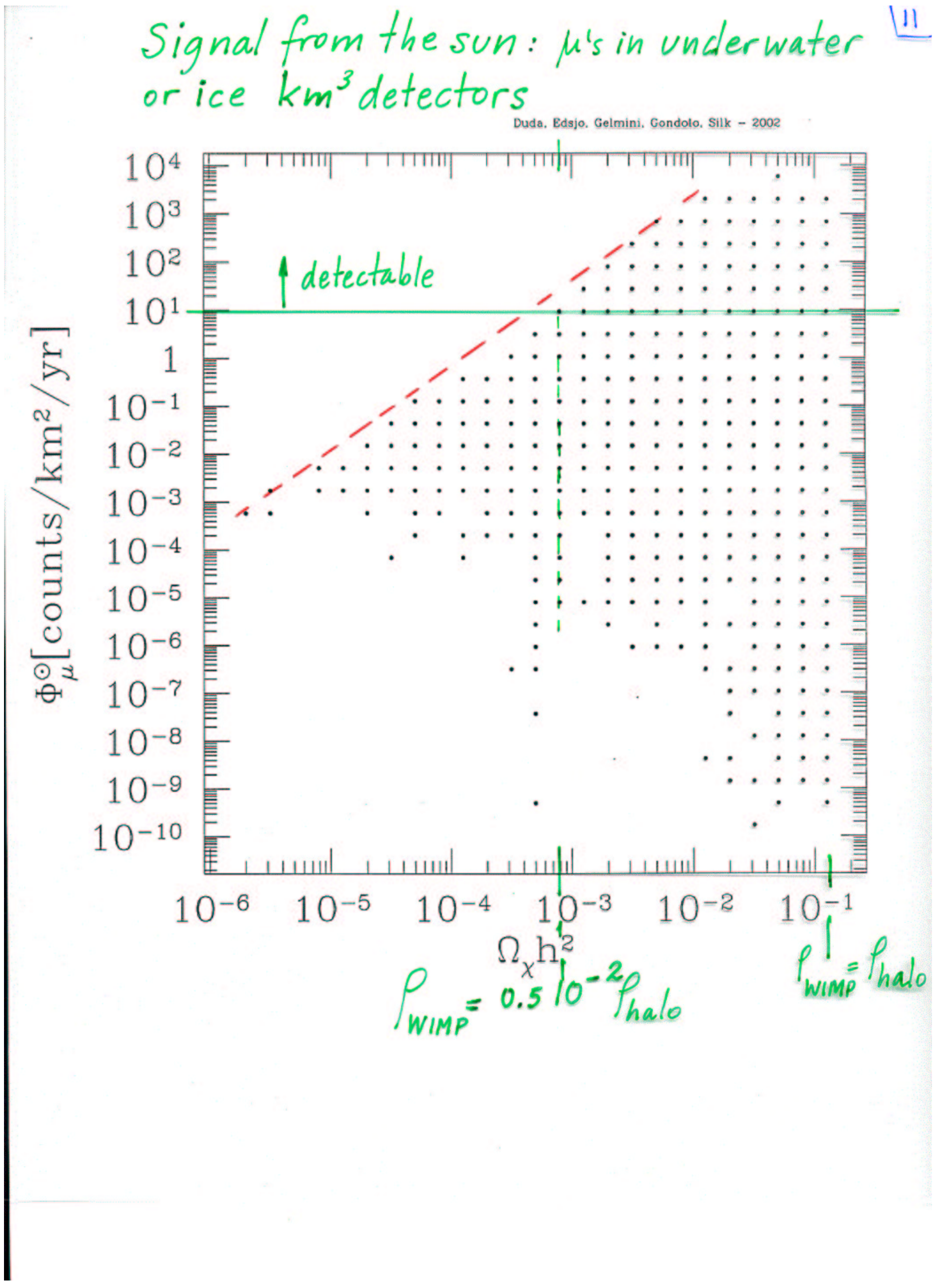
Rate of annihilation in the halo $\sim \sigma_a \rho_\chi^2 \sim \Omega_\chi$

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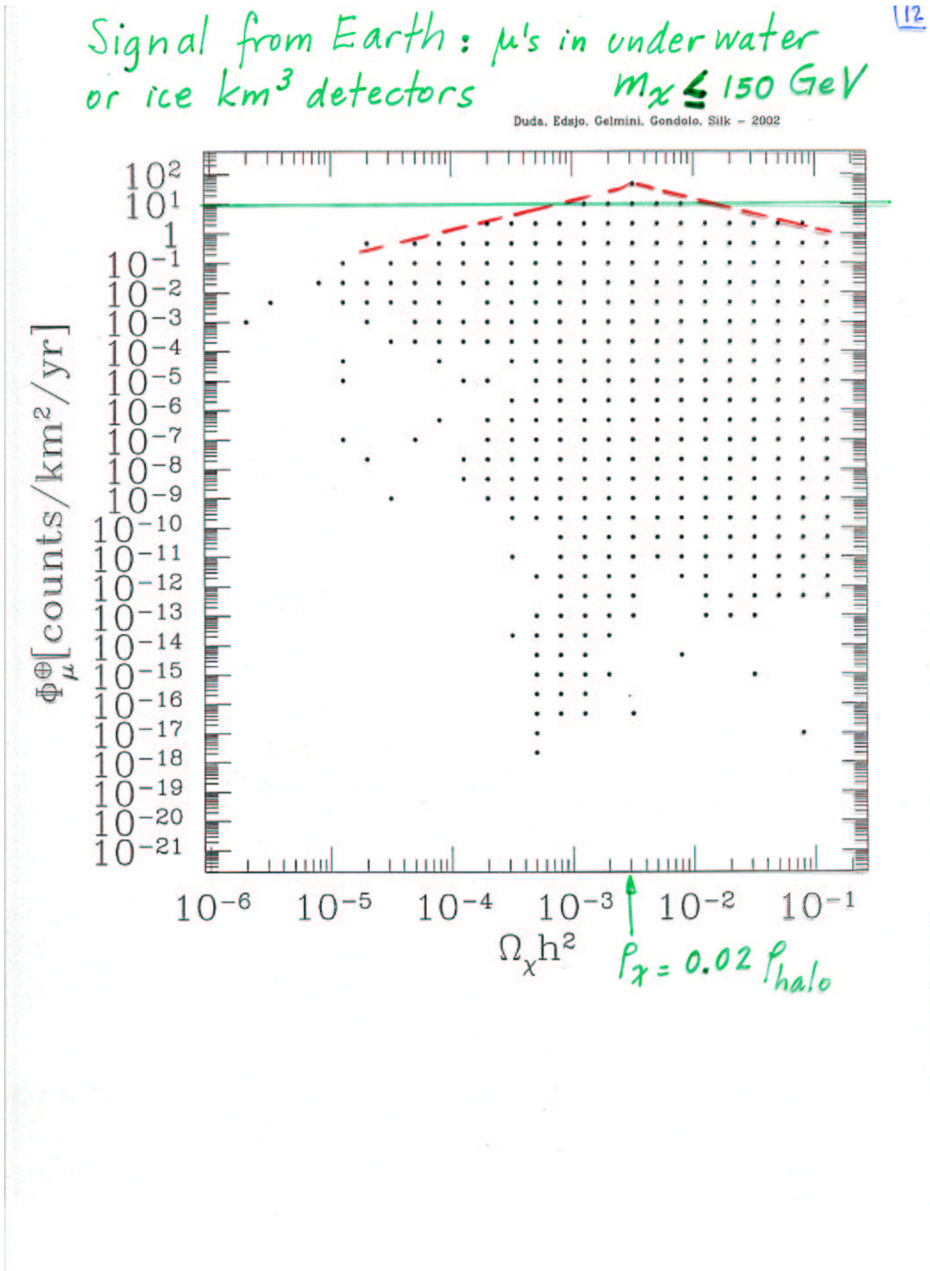
Signal from the sun: μ's in underwater or ice km³ detectors
Duda, Edsjo, Gelmini, Gondolo, Silk – 2002
detectable
$\Phi_\mu^\odot$[counts/km²/yr]
$\Omega_\chi h^2$
$\rho_{WIMP} = 0.5\ 10^{-2} \rho_{halo}$
$\rho_{WIMP} = \rho_{halo}$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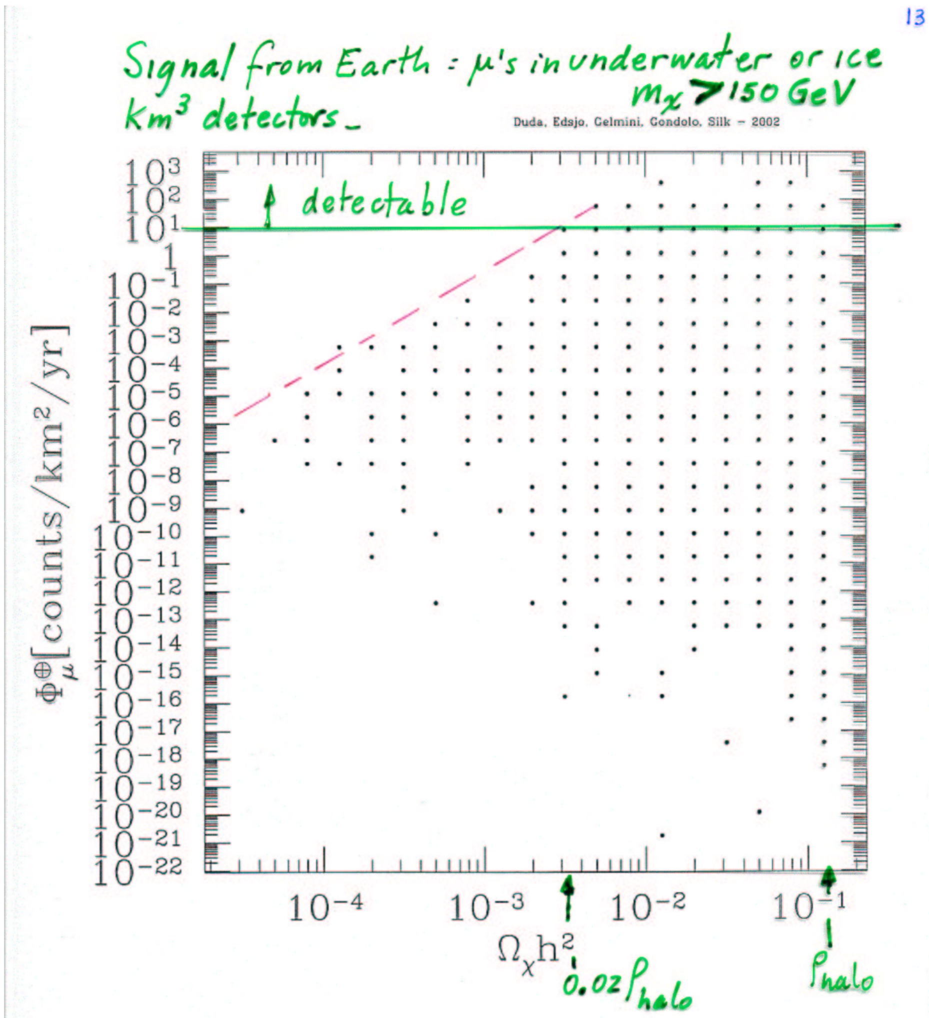
Signal from Earth: μ's in underwater or ice km³ detectors
$m_\chi \leq 150$ GeV
Duda, Edsjo, Gelmini, Gondolo, Silk – 2002
$\Phi_\mu^\oplus$[counts/km²/yr]
$\Omega_\chi h^2$
$\rho_\chi = 0.02\ \rho_{halo}$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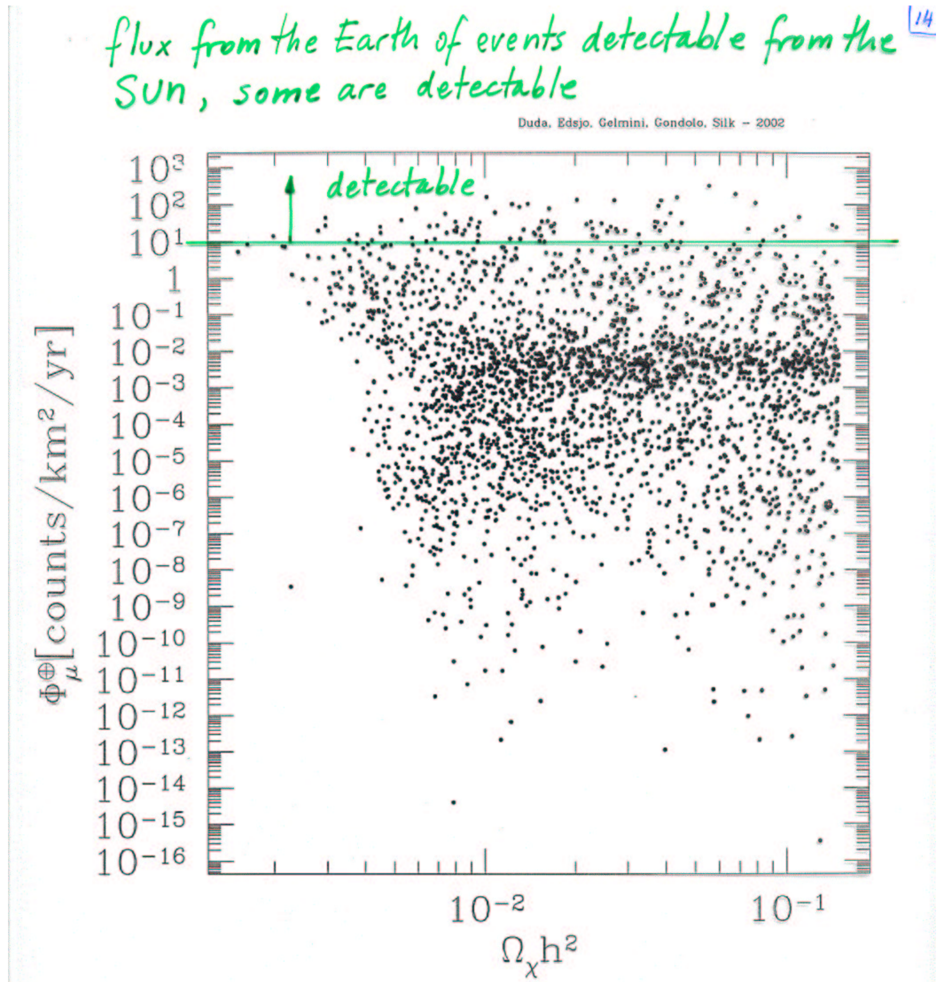
Signal from Earth: μ's in underwater or ice km³ detectors
$m_\chi > 150$ GeV
Duda, Edsjo, Gelmini, Gondolo, Silk – 2002
detectable
$\Phi_\mu^\oplus$[counts/km²/yr]
$\Omega_\chi h^2$
0.02 ρ_{halo}
ρ_{halo}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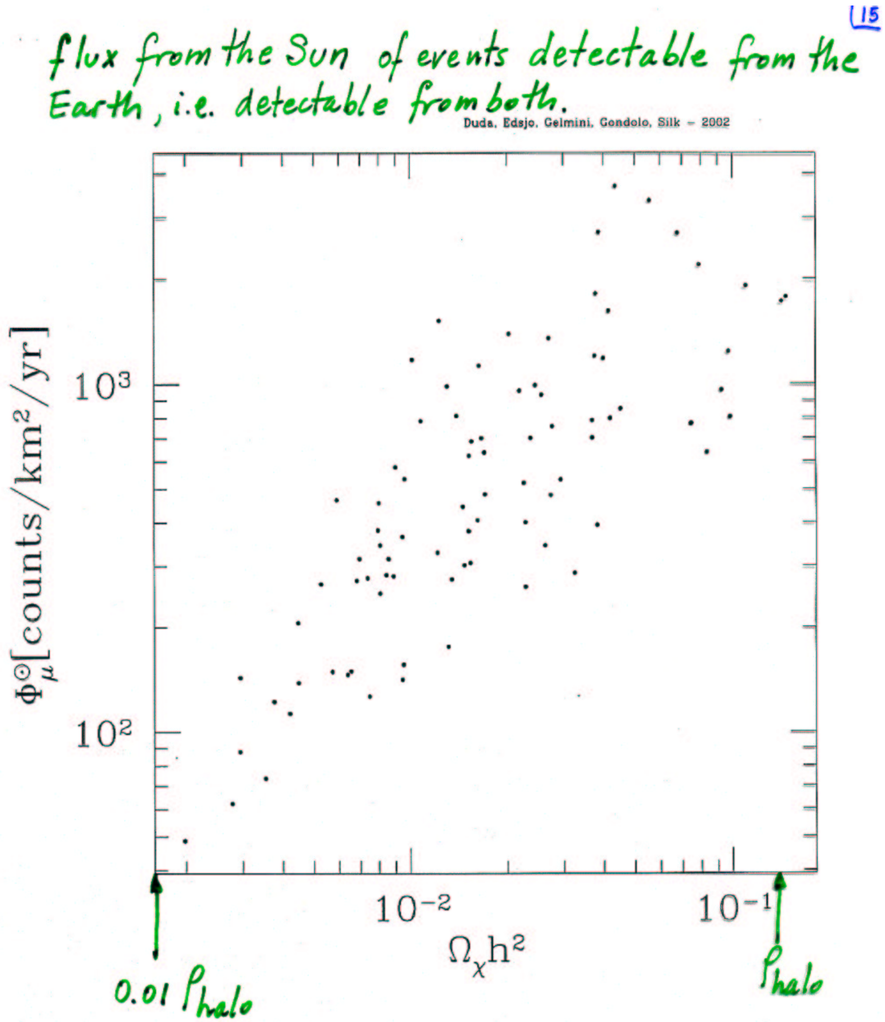
flux from the Earth of events detectable from the Sun, some are detectable
Duda, Edsjo, Gelmini, Gondolo, Silk – 2002
detectable
$\Phi_\mu^\oplus$[counts/km²/yr]
$\Omega_\chi h^2$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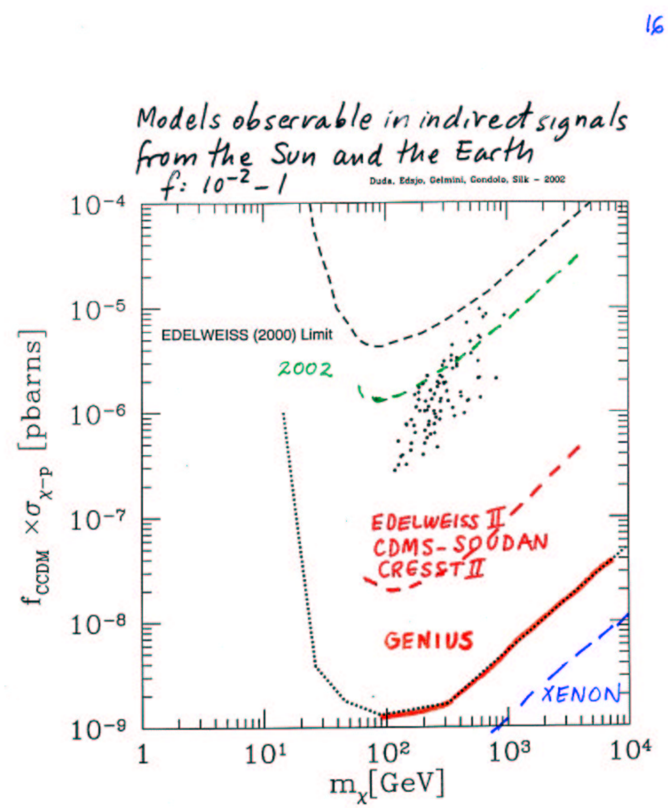
flux from the Sun of events detectable from the Earth, i.e. detectable from both.
Duda, Edsjo, Gelmini, Gondolo, Silk – 2002
$\Phi_\mu^\odot$[counts/km²/yr]
10^3
10^2
10^{-2}
10^{-1}
$\Omega_\chi h^2$
0.01 ρ_{halo}
ρ_{halo}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Models observable in indirect signals from the Sun and the Earth
f: 10^{-2} – 1
Duda, Edsjo, Gelmini, Gondolo, Silk – 2002
EDELWEISS (2000) Limit
2002
EDELWEISS II
CDMS-SOUDAN
CRESST II
GENIUS
XENON
$f_{CCDM} \times \sigma_{\chi-p}$ [pbarns]
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
1
10^1
10^2
10^3
10^4
m_χ[GeV]

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Conclusions on Detectability of Subdominant WIMPs

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- If a DM signal is seen
  - soon in direct detection experiments
  - in km^3 detectors from neutralino annihilations in the Sun or the Earth (indirect detection)

it could come from neutralinos with **density fraction $f = 1$ to 0.01**

- Future direct DM searches could see,
  - CDMS-SOUDAN, EDELWEISS II, CRESST II ... **to $f \simeq 10^{-3}$**
  - GENIUS .... **to $f \simeq 10^{-4}$**
  - XENON .... **to $f \simeq 10^{-5}$**

- A signal from annihilations in the halo => **$f \simeq 1$** (fluxes decrease as $\Omega^{-1}_{WIMP} \sim f$)

- Some discrimination of f is possible, if a signal is seen in **1-** direct, indirect from **2-** Sun or **3-** Earth searches: some models imply signals in all three, some in two, some in only one