Dark Matter Candidates

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Outline

• Evidence for Dark Matter
• Dark Matter properties
• neutrinos
• axions
• WIMP candidates from UED, Little Higgs, SUSY
• The neutralino
  • Relic abundance
  • Direct detection
• Conclusions
• Topics covered by other talks:
  • Experimental direct searches (Pierluigi Belli, Dan Bauer)
  • Indirect detection – theory (Lars Bergström)
  • Indirect detection – experiment (Piergiorgio Picozza)
Evidence for Dark Matter

• Spiral galaxies
  • rotation curves
• Clusters & Superclusters
  • Weak gravitational lensing
  • Strong gravitational lensing
  • Galaxy velocities
  • X rays
• Large scale structure
  • Structure formation
• CMB anisotropy: WMAP
  • $\Omega_{\text{tot}} = 1$
  • $\Omega_{\text{dark energy}} \sim 0.7$
  • $\Omega_{\text{matter}} \sim 0.27$
  • $\Omega_{\text{baryons}} \sim 0.05$

$\Omega_{\text{dark matter}} \sim 0.22$

TAUP 2007, Sendai, September 11-15 2007
The properties of a good Dark Matter candidate:

- stable (protected by a conserved quantum number)
- no charge, no colour (weakly interacting)
- cold, non dissipative
- relic abundance compatible to observation
- motivated by theory (vs. “ad hoc”)

Subdominant candidates – variety is common in Nature → may be easier to detect
The first place to look for a DM candidate...

<table>
<thead>
<tr>
<th>GAUGE</th>
<th>Gauge bosons</th>
<th>((\text{SU}(3)_c, \text{SU}(2)_L))</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-boson</td>
<td>(A^{(1)}<em>\mu = B</em>\mu)</td>
<td>((1, 1)_0)</td>
</tr>
<tr>
<td>W-bosons</td>
<td>(A^{(2)}<em>\mu = W^\alpha</em>\mu)</td>
<td>((1, 3)_0)</td>
</tr>
<tr>
<td>gluon</td>
<td>(A^{(3)}<em>\mu = G^\alpha</em>\mu)</td>
<td>((8, 1)_0)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MATTER</th>
<th>Fermions</th>
<th>((\text{SU}(3)_c, \text{SU}(2)_L))</th>
</tr>
</thead>
<tbody>
<tr>
<td>leptons</td>
<td>(</td>
<td>L^I = \begin{pmatrix} \nu^I_L \ e^-_L \end{pmatrix} )</td>
</tr>
<tr>
<td>quarks</td>
<td></td>
<td>((1, 1)_{+2})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>((8, 2)_{+\frac{1}{2}})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>((3, 1)_{-\frac{2}{3}})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>((3, 1)_{+\frac{2}{3}})</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HIGGS</th>
<th>Higgs Boson</th>
<th>((\text{SU}(3)_c, \text{SU}(2)_L))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higgs</td>
<td>(\phi = \begin{pmatrix} \phi^+ \ \phi^0 \end{pmatrix} )</td>
<td>((1, 2)_{+1})</td>
</tr>
</tbody>
</table>
Neutrino

- $\sum m_\nu < 0.66 \text{ eV} \quad \text{(WMAP+LSS+SN)}$
- LEP:
  $N_\nu = 2.994 \pm 0.012$
  $\rightarrow m_\nu \geq 45 \text{ GeV}$
  $\rightarrow \Omega_\nu h^2 \leq 10^{-3}$
- DM searches exclude:
  $10 \text{ GeV} \leq m_\nu \leq 5 \text{ TeV}$
  (similar constraints for sneutrinos and KK-neutrinos)

mix with sterile component
(both for neutrinos and sneutrinos)

$\Omega_\nu h^2 = \frac{\sum m_\nu}{91.5 \text{ eV}}$

$\Omega_\nu h^2 \propto <\sigma_{\text{ann}}\nu>^{-1}$
beyond the standard model
(Incomplete) List of DM candidates

- RH neutrinos
- Axions
- Lightest Supersymmetric particle (LSP) – neutralino, sneutrino, axino
- Lightest Kaluza-Klein Particle (LKP)
- Heavy photon in Little Higgs Models
- Solitons (Q-balls, B-balls)
- Black Hole remnants
- ...
The axion

- Pseudo Goldstone boson of Peccei-Quinn symmetry introduced to explain CP conservation in QCD: \( \varphi = F e^{i\theta} \)

\[
m_a \simeq 0.62 \text{ eV} \left( \frac{10^7 \text{GeV}}{f_a} \right)
\]

- 3 productions mechanisms in the early Universe:
  1) misalignment \( (T>\Lambda_{\text{QCD}}) \) +coherent oscillations around minimum \( (T<\Lambda_{\text{QCD}}) \):

\[
\Omega_a h^2 = k_a \left( \frac{m_a}{10^{-5} \text{eV}} \right)^{-1.175} < \theta_i^2 > \text{ if no inflation after PQ phase trans.}
\]

(0.3 < k_a < a few)

2) axion strings \( (T_R>f_a) \)

3) thermal \( (m_a>10^{-3} \text{ eV}, \text{ subdominant}) \)

\[\text{average} \quad \text{(flat dist.} \rightarrow <\theta^2>=\pi^2/3) \rightarrow m_a \sim 10^{-5} \text{ eV} \]

otherwise: smaller \( m_a \) possible

[Tegmark, Aguirre, Rees. Wilczek]
Experimental limits:

use data from WIMP searches! (but sensitivity improves as $(MT)^{1/8}$)

$g_{a\gamma\gamma}$ from theory & uncertainty in the masses of light quarks, (Buckley, Murayama, arXiv:0705.0542)
most popular DM candidates from particle physics
(solve hierarchy problem: $M_W/M_{Pl} \sim 10^{-16}$)

<table>
<thead>
<tr>
<th>conserved symmetry</th>
<th>DM candidate</th>
</tr>
</thead>
<tbody>
<tr>
<td>• susy R-parity $\chi$ (neutralino)</td>
<td></td>
</tr>
<tr>
<td>• extra dimensions K-parity $B^{(1)}$ (KK photon)</td>
<td></td>
</tr>
<tr>
<td>• little Higgs T-parity $B_H$ (heavy photon)</td>
<td></td>
</tr>
</tbody>
</table>

all thermal candidates, massive, with weak-type interactions (WIMPs)
the thermal cosmological density of a WIMP $X$

$$\Omega_X h^2 \sim 1/\langle \sigma_{\text{ann}} v \rangle_{\text{int}}$$

$$\langle \sigma_{\text{ann}} v \rangle_{\text{int}} = \int_{x_f}^{x_0} \langle \sigma_{\text{ann}} v \rangle dx$$

$x_0 = M/T_0$

$T_0 =$ present (CMB) temperature

$x_f = M/T_f$

$T_f =$ freeze-out temperature

$X_f >> 1$, $X$ non relativistic at decoupling, low temp expansion for

$$\langle \sigma_{\text{ann}} v \rangle: \langle \sigma_{\text{ann}} v \rangle \sim a + b/x$$

if $\sigma_{\text{ann}}$ is given by weak-type interactions $\rightarrow \Omega_X \sim 0.1-1$

... + coannihilations with other particle(s)

close in mass + resonant annihilations

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WIMP direct detection

- Elastic recoil of non relativistic halo WIMPs off the nuclei of an underground detector
- Recoil energy of the nucleus in the keV range
- Yearly modulation effect due to the rotation of the Earth around the Sun (the relative velocity between the halo, usually assumed at rest in the Galactic system, and the detector changes during the year)

\[ v_0 = 232 \text{ km/sec} \]
\[ v_\odot = 30 \text{ km/sec} \]
WIMP differential detection rate

\[
\frac{dR}{dE_R} = N_T \frac{\rho_\chi}{m_\chi} \int_{v_{min}}^{v_{max}} d\vec{v} f(\vec{v}) |\vec{v}| \frac{d\sigma(\vec{v}, E_R)}{dE_R}
\]

- \(E_R\) = nuclear energy
- \(N_T\) = # of nuclear targets
- \(v\) = WIMP velocity in the Earth’s rest frame

### Astrophysics
- \(\rho_\chi\) = WIMP local density
- \(f(\vec{v})\) = WIMP velocity distribution function

### Particle and nuclear physics
- \(\frac{d\sigma(\vec{v}, E_R)}{dE_R}\) = WIMP-nucleus elastic cross section

\[
\frac{d\sigma(\vec{v}, E_R)}{dE_R} = \left(\frac{d\sigma(\vec{v}, E_R)}{dE_R}\right)_{\text{coherent}} + \left(\frac{d\sigma(\vec{v}, E_R)}{dE_R}\right)_{\text{spin-dependent}}
\]

usually dominates, \(\alpha\) (atomic number)\(^2\)

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Different halo models are possible

[Belli, Cerulli, Fornengo, Scopel]

### Class A: Spherical $\rho_{\text{DM}}$, isotropic velocity dispersion

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>$R_e$</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>Isothermal sphere</td>
<td>5 kpc</td>
<td>Eq. (20)</td>
</tr>
<tr>
<td>A1</td>
<td>Evans' logarithmic [15]</td>
<td>$R_e = 5$ kpc</td>
<td>Eq. (18)</td>
</tr>
<tr>
<td>A2</td>
<td>Evans' power-law [16]</td>
<td>$R_e = 16$ kpc, $\beta = 0.7$</td>
<td>Eq. (23)</td>
</tr>
<tr>
<td>A3</td>
<td>Evans' power-law [16]</td>
<td>$R_e = 2$ kpc, $\beta = 0.1$</td>
<td>Eq. (23)</td>
</tr>
<tr>
<td>A4</td>
<td>Jaffe [14]</td>
<td>Table I</td>
<td>Eq. (26)</td>
</tr>
<tr>
<td>A5</td>
<td>NFW [18]</td>
<td>Table I</td>
<td>Eq. (26)</td>
</tr>
<tr>
<td>A6</td>
<td>Moore et al. [19]</td>
<td>Table I</td>
<td>Eq. (26)</td>
</tr>
<tr>
<td>A7</td>
<td>Kravtsov et al. [20]</td>
<td>Table I</td>
<td>Eq. (26)</td>
</tr>
</tbody>
</table>

### Class B: Spherical $\rho_{\text{DM}}$, non-isotropic velocity dispersion (Ostriakov-Merrit, $\beta_e = 0.4$)

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>$R_e$</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Evans' logarithmic</td>
<td>$R_e = 5$ kpc</td>
<td>Eqs. (18),(28)</td>
</tr>
<tr>
<td>B2</td>
<td>Evans' power-law</td>
<td>$R_e = 16$ kpc, $\beta = 0.7$</td>
<td>Eqs. (23),(28)</td>
</tr>
<tr>
<td>B3</td>
<td>Evans' power-law</td>
<td>$R_e = 2$ kpc, $\beta = 0.1$</td>
<td>Eqs. (23),(28)</td>
</tr>
<tr>
<td>B4</td>
<td>Jaffe</td>
<td>Table I</td>
<td>Eqs. (26),(28)</td>
</tr>
<tr>
<td>B5</td>
<td>NFW</td>
<td>Table I</td>
<td>Eqs. (26),(28)</td>
</tr>
<tr>
<td>B6</td>
<td>Moore et al.</td>
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<td>B7</td>
<td>Kravtsov et al.</td>
<td>Table I</td>
<td>Eqs. (26),(28)</td>
</tr>
</tbody>
</table>

### Class C: Axisymmetric $\rho_{\text{DM}}$

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>$R_e$</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Evans' logarithmic</td>
<td>$R_e = 0$, $q = 1/\sqrt{3}$</td>
<td>Eqs. (33),(34)</td>
</tr>
<tr>
<td>C2</td>
<td>Evans' logarithmic</td>
<td>$R_e = 5$ kpc, $q = 1/\sqrt{3}$</td>
<td>Eqs. (33),(34)</td>
</tr>
<tr>
<td>C3</td>
<td>Evans' power-law</td>
<td>$R_e = 16$ kpc, $q = 0.05$, $\beta = 0.9$</td>
<td>Eqs. (37),(38)</td>
</tr>
<tr>
<td>C4</td>
<td>Evans' power-law</td>
<td>$R_e = 2$ kpc, $q = 1/\sqrt{3}$, $\beta = 0.1$</td>
<td>Eqs. (37),(38)</td>
</tr>
</tbody>
</table>

### Class D: Triaxial $\rho_{\text{DM}}$ [17] ($q = 0.8, p = 0.9$)

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>$\delta$</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>Earth on major axis, radial anisotropy</td>
<td>$-1.78$</td>
<td>Eqs. (43),(44)</td>
</tr>
<tr>
<td>D2</td>
<td>Earth on major axis, tangential anisotropy</td>
<td>$1$</td>
<td>Eqs. (43),(44)</td>
</tr>
<tr>
<td>D3</td>
<td>Earth on intermediate axis, radial anisotropy</td>
<td>$-1.78$</td>
<td>Eqs. (43),(44)</td>
</tr>
<tr>
<td>D4</td>
<td>Earth on intermediate axis, tangential anisotropy</td>
<td>$1$</td>
<td>Eqs. (43),(44)</td>
</tr>
</tbody>
</table>

Sizeable variation of the local density: $0.17 < \rho < 1.7$
The KK photon in Universal Extra Dimensions (UED)


• all SM fields propagate in the 5th dimension
• dispersion relation in 5 dim:
  \[ E^2 = p^2 + (p_5^2 + M^2) \]

implies an infinite tower of KK massive states
in the effective 4-dim theory, since \( p_5 = n/R \)
(\( R^{-1} > 300 \) GeV from EW tests, \( n = 0, 1, 2, 3, \ldots \))
• compactification on \( S_1/Z_2 \):
  \[ \mathcal{P}_{Z_2} \phi(x, y) = \eta \phi(x, -y) \]

allows to get rid of unwanted dof at zero
level \( \rightarrow \) translational invariance broken in 5th dim
• residual invariance under discrete \( \pi R \) translations
  \( \rightarrow \) KK parity \( (-1)^n \) is conserved \( \rightarrow \) LKP (Lightest KK particle) is stable
• 1-loop corrections (Cheng & al, 2002):
  LKP = 1st excitation of weak hypercharge boson \( B^{(1)} \)
B\(^{(1)}\) relic abundance

[Servant, Tait, NPB650, 391; New J. Phys. 4, 99; Kakizai & al., PRD71, 123522; Kong, Matchev, JHEP0601, 038]

• coannihilations (many modes with similar masses)
• resonances (\(M_{NLKP} \sim 2 \times M_{LKP}\))

• general rule of coannihilation:

if cohannihilating particle annihilates faster than LKP→ smaller relic abundance
slower than LKP→ larger relic abundance
both cases are possible: KK quarks and gluons vs. KK leptons

\(\Omega_B h^2 = 0.1\)

\(\Delta = \text{fractional mass splitting}\)
• low direct detection signals:

\[ \Delta \equiv \frac{m_{q_1} - m_{B_1}}{m_{B_1}} \]
Right-handed KK-neutrino Dark Matter:
see talk by M. Yamanaka in parallel session
Supersymmetry and Dark Matter

Supersymmetry:
fundamental \leftrightarrow bosons

<table>
<thead>
<tr>
<th>R=1</th>
<th>R=-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>leptons, quarks</td>
<td>\leftrightarrow</td>
</tr>
<tr>
<td>gauge fields</td>
<td>\leftrightarrow</td>
</tr>
<tr>
<td>Higgs fields</td>
<td>\leftrightarrow</td>
</tr>
</tbody>
</table>

R-parity conservation forbids
barion number violation
at the tree level

...and prevents the decay of the Lightest Susy Particle (LSP)
THE LSP CAN BE THE DARK MATTER

GUT unification of gauge couplings
The neutralino

The neutralino is defined as the lowest-mass linear superposition of bino $\tilde{B}$, wino $\tilde{W}^{(3)}$ and the two higgsino states $\tilde{H}_1^0$, $\tilde{H}_2^0$:

$$\chi \equiv a_1 \tilde{B} + a_2 \tilde{W}^{(3)} + a_1 \tilde{H}_1^0 + a_1 \tilde{H}_2^0$$

neutral, colourless, only weak-type interactions

stable if R-parity is conserved, thermal relic

non relativistic at decoupling $\rightarrow$ Cold Dark Matter (required by CMB data + structure formation models)

relic density can be compatible with cosmological observations: $0.095 \leq \Omega_\chi h^2 \leq 0.131$

$\rightarrow$ IDEAL CANDIDATE FOR COLD DARK MATTER
Right-handed sneutrino Dark Matter: see talk by T. Asaka in parallel session
Supergravity-inspired models (SUGRA)

GUT-scale \( (M_{\text{GUT}} \approx 10^{16} \text{ GeV}) \) relations:

- Unification of gaugino masses:
  \[ M_i(M_{\text{GUT}}) \equiv m_{1/2} \]

- Unification of scalar masses:
  \[ m_i(M_{\text{GUT}}) \equiv m_0 \]

- Universality of trilinear couplings:
  \[ A^u(M_{\text{GUT}}) = A^d(M_{\text{GUT}}) = A^l(M_{\text{GUT}}) \equiv A_0 m_0 \]

- Other parameters: \( \text{sign}(\mu), \tan \beta \)

RGE evolution of parameters down to the EW scale

Radiative Electro Weak Symmetry Breaking (REWSB):

Typical predictions:
- \( \chi \to \text{gaugino} \) (except “focus point region”, \( m_0 \gg m_{1/2} \))
- \( m_A \gg O(m_Z) \) unless \( \tan \beta \geq 50 \)
- \( \mu-M_2 \) correlation
- \( m_{\text{quark}} > m_{\text{slepton}} \)

Deviations from universality at \( M_{\text{GUT}} \) or a different unification scale imply significant modifications of these properties
SUGRA (a.k.a. CMSSM)

**stau coannihilation**

- Focus point
  - Only few regions cosmologically allowed
  - Variants (e.g. non-universality of soft masses at the GUT scale or lower unification scale) that increase Higgsino content of the neutralino → lower relic abundance and higher signals

**Higgs funnel**

[Ellis, Olive, Santoso, Spanos]

[Feng, Machev, Moroi, Wilczek]
Direct detection in SUGRA

[Ellis, Olive, Santoso, Spanos]

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The Next-to-Minimal MSSM (NMSSM) solves the μ problem, i.e. why μ~M_{EW} in: μH_1H_2

superpotential:

\[ W = \epsilon_{ij} \left( Y_u H_2^j Q^i u + Y_d H_1^i Q^j d + Y_e H_1^i L^j e \right) - \epsilon_{ij} \lambda S H_1^i H_2^j + \frac{1}{3} \kappa S^3 \]

Higgs soft terms in the NMSSM:

\[ -L_{\text{soft}}^{Higgs} = m_{H_i}^2 H_i^* H_i + m_S^2 S^* S + (-\epsilon_{ij} \lambda A_\lambda S H_1^i H_2^j + \frac{1}{3} \kappa A_\kappa S^3 + \text{H.c.}) \]

NMSSM particle content:

\[ \text{MSSM+} \]

2 Higgs (CP-even, CP-odd)

1 neutralino dof

The lightest neutralino:

\[ \tilde{\chi}_1^0 = N_{11} \tilde{B}^0 + N_{12} \tilde{W}_3^0 + N_{13} \tilde{H}_1^0 + N_{14} \tilde{H}_2^0 + N_{15} \tilde{S} \]

CP-even Higgs:

\[ h_1^0 = S_{11} H_1^0 + S_{12} H_2^0 + S_{13} S \]
Relic density and direct detection rate in NMSSM
[Cerdeño, Hugonie, López-Fogliani, Muñoz, Teixeira]

\[ M_1 = 160 \text{ GeV}, \quad M_2 = 320, \quad A_\lambda = 400 \text{ GeV}, \quad A_k = -200 \text{ GeV}, \quad \mu = 130 \text{ GeV}, \quad \tan \beta = 5 \]

(sizeable direct detection)

- very light neutral Higgs (mainly singlet)
- light scalars imply more decay channels and resonant decays
- neutralino relatively light (< decay thresholds) and mostly singlino
- high direct detection cross sections (even better for lower \( M_1 \))

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**Effective MSSM:** effective model at the EW scale with a few MSSM parameters which set the most relevant scales

- $M_1$ U(1) gaugino soft breaking term
- $M_2$ SU(2) gaugino soft breaking term
- $\mu$ Higgs mixing mass parameter
- $\tan \beta$ ratio of two Higgs v.e.v.’s
- $m_A$ mass of CP odd neutral Higgs boson (the extended Higgs sector of MSSM includes also the neutral scalars $h, H$, and the charged scalars $H^{\pm}$)
- $m_{\tilde{q}}$ soft mass common to all squarks
- $m_{\tilde{\ell}}$ soft mass common to all sleptons
- $A$ common dimensionless trilinear parameter for the third family ($A_{\tilde{b}} = A_{\tilde{\tau}} \equiv Am_{\tilde{q}}; A_{\tilde{\tau}} \equiv Am_{\tilde{\ell}}$)
- $R \equiv M_1 / M_2$

**SUGRA $\rightarrow R = 0.5$**
Can the neutralino be light?

Lower limits on the neutralino mass from accelerators

- **Indirect** limits from chargino production \((e^+e^- \rightarrow \chi^+\chi^-)\):

\[
m_{\chi^\pm} \gtrsim 100 \text{ GeV} \Rightarrow m_{\chi} \gtrsim 50 \text{ GeV} \quad \text{if} \quad R \equiv \frac{M_1}{M_2} = \frac{5}{3} \tan^2 \theta_w
\]

- **Direct** limits from \(e^+e^- \rightarrow \chi_0^i\chi_0^j\) \((\chi_0^1 \equiv \chi, m_{\chi_0^1} < m_{\chi_0^2} < m_{\chi_0^3} < m_{\chi_0^4})\)†:
  - Invisible width of the Z boson (upper limit on number \(N_\nu\) of neutrino families)
  - Missing energy + photon(s) or \(f\bar{f}\) from \(\chi_0^{i>1} \rightarrow \chi_0^1\) decay

- **Direct** limits from \(\tilde{t} \rightarrow c\chi\) and \(\tilde{b} \rightarrow b\chi\) at Tevatron ‡

  † small production cross sections
  ‡ light squark masses (\(\lesssim 100\ \text{GeV}\)) required

⇒ No absolute **direct** lower bounds on \(m_{\chi}\)
Cosmological lower bound on $m_\chi$

[Bottino, Fornengo, Scopel, PRD68,043506]

upper bound on $\Omega_{CDM}h^2$

curve: analytical approximation for minimal $\Omega_{CDM}h^2$

scatter plot: full calculation

$M_1<<M_2, \mu$

$m_\chi [1 - m_b^2/m_\chi^2]^{1/4} \gtrsim 5.3 \text{ GeV} \left(\frac{m_A}{90 \text{ GeV}}\right)^2$

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Neutralino - nucleon cross section

tight correlation between relic abundance and \( \chi \)-nucleon cross section:

\[
\Omega_\chi h^2 \leq (\Omega_{CDM} h^2)_{\max}
\]

\[
\sigma^{(\text{nucleon})}_{\text{scalar}} \geq \frac{10^{-40} \text{cm}^2}{(\Omega_{CDM} h^2)_{\max}} \frac{\text{GeV}^2}{m_\chi^2 |1-m_\chi^2/m_\chi^2|^{1/2}} \quad \text{for } m_\chi \lesssim 20 \text{ GeV}
\]

The elastic cross section is bounded from below

→ “funnel” at low mass

DAMA modulation region, likelihood function values distant more than 4 \( \sigma \) from the null result (absence on modulation) hypothesis, Riv. N. Cim. 26 n. 1 (2003) 1-73, astro-ph/0307403

Color code:

- \( \Omega_\chi h^2 < 0.095 \)
- \( \times \Omega_\chi h^2 > 0.095 \)
How exp. limit change with different halo models (CDMS):

A: Spherical \( \rho_{\text{DM}} \), isotropic velocity dispersion
- A0: Isothermal sphere
- A1: Evans’ logarithmic [14]
- A2: Evans’ power-law [15]
- A5: NFW [16]

B: Spherical \( \rho_{\text{DM}} \), non-isotropic velocity dispersion
- B1: Evans’ logarithmic [14]
- B5: NFW [16]

C: Axisymmetric \( \rho_{\text{DM}} \)
- C2: Evans’ logarithmic
- C3: Evans’ power-law

D: Triaxial \( \rho_{\text{DM}} \) [17]
- D1: Earth on major axis, radial anisotropy

largest uncertainty at low masses from high velocity tail of the distribution


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Conclusions

• WIMPs at the TeV scale can be realized in different well-motivated scenarios (KK photon in UED, Heavy photon in Little Higgs, neutralino in SUSY) +"Minimal” extensions of SM (talk by Tytgat in parallel session)
• they can all provide the Cold Dark Matter with the correct abundance
• neutralino is still the most popular. Today available in different flavours: SUGRA, nuSUGRA, sub-GUT, Mirage mediation, NMSSM, effMSSM, CPV,…
• neutralinos can be light
• astrophysical uncertainties in signal predictions
• direct searches are already exploring some SUSY scenarios