Title: Resonant scattering and recombination of pseudo-degenerate WIMPs

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Abstract: WIMP dark matter candidates chi^0 have interesting signatures for direct and indirect detection in regimes where there is a near degeneracy with a heavier charged state chi^{pm}, as occurs for example along the boundary of the coannihilation strip in the CMSSM. For small splittings of O(10) MeV, the scattering of WIMPs off nuclei may be dominated by inelastic recombination processes mediated by the formation of (chi^- N) bound states, leading for example to a distinct signature for direct detection. I will discuss these and other resonant processes that distinguish the detection signatures of this class of WIMP scenarios.

PASCOS - Perimeter Institute - June '08

Resonant scattering and recombinaton of pseudo-degenerate WIMP dark matter

Adam Ritz
University of Victoria

With M. Pospelov, 0803.2251

Evidence for (nonbaryonic) Dark Matter

Over many scales…

- galaxy rotation curves
- clusters (lensing)
- structure formation
- CMB
- cosmology vs BBN

[D. Clowe et al. '06]

Strong motivation for exploring all possible signatures for direct (terrestrial) or indirect (astrophysical) detection

Plan of the talk

- Introduction
  - WIMP dark matter paradigm: tensions and hints…
- Pseudo-degenerate WIMPs
  - Direct detection - ‘recombination’
  - Indirect detection - annihilation and 511 keV line
- Conclusions

The WIMP paradigm

Thermal relic: $\frac{dn_\chi}{dt} = -3Hn_\chi - (n_\chi^2 - n_{eq}^2)\langle\sigma_{\rm ann}v\rangle$

Roughly: $\Omega_\chi h^2 \sim \frac{3\times10^{-27}cm^3s^{-1}}{\langle\sigma_{\rm ann}v\rangle}$ [Lee & Weinberg '77]

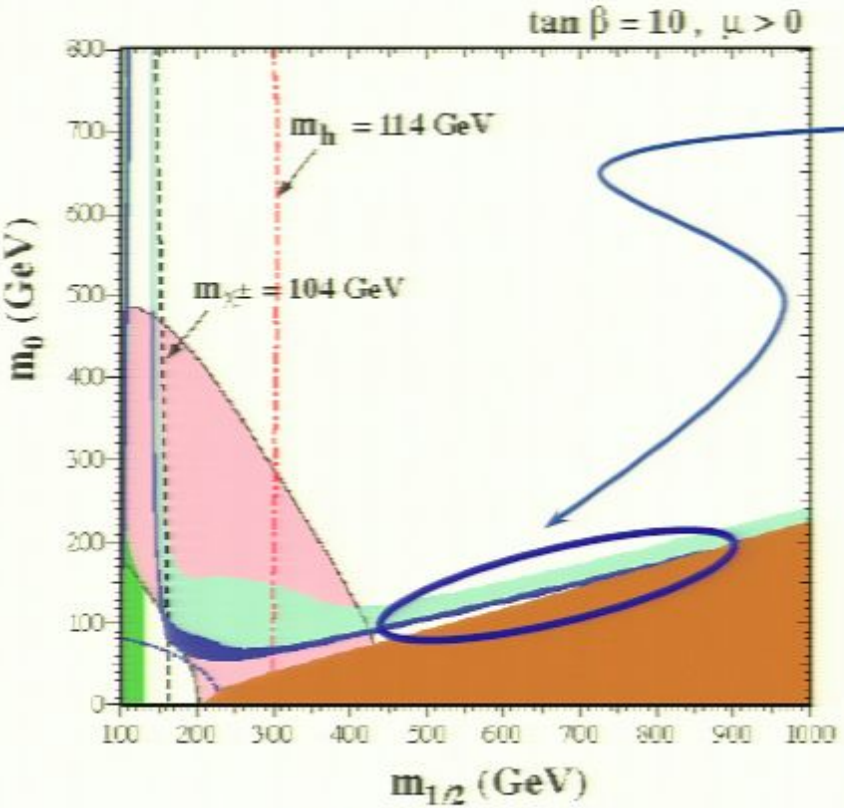
[WMAP5 $\Rightarrow$ $\Omega_\chi h^2 = 0.1120 \pm 0.008$]

For a WIMP: $\langle\sigma_{\rm ann}v\rangle \sim \frac{\alpha^2}{m_\chi^2}$

$\Rightarrow$ $m_\chi \sim \mathcal{O}(100\ \text{GeV})$

Problems or Hints?

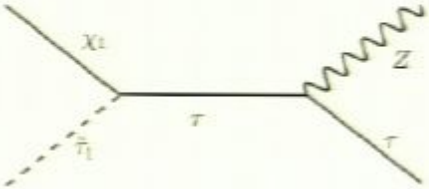
In more detail (e.g. CMSSM) …



WMAP strip

$\Delta(m_{\tilde{\tau}} - m_{\chi}) \leq 5\,GeV$

relic density requires efficient co-annihilation



[J. Ellis et al. '03]

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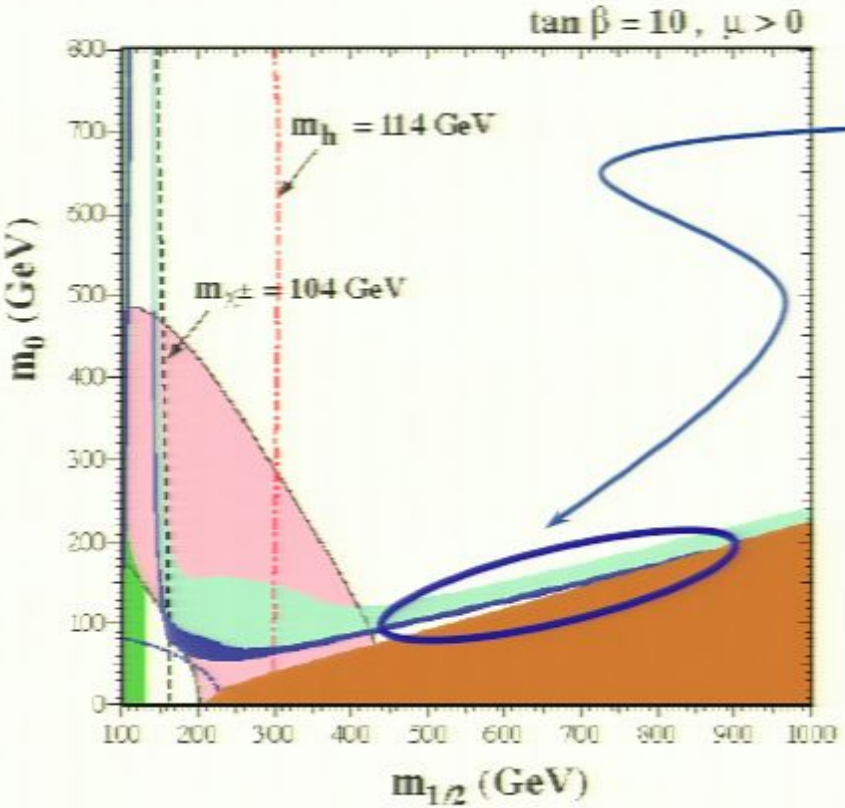

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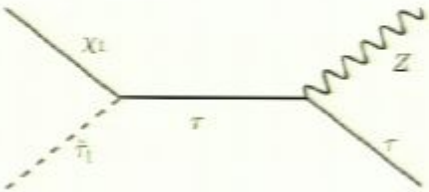

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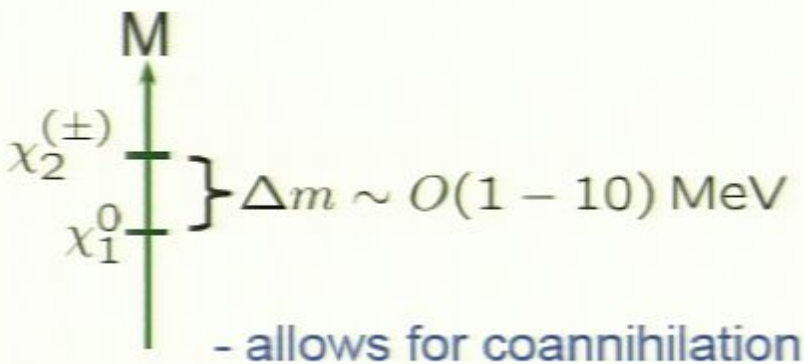
Pseudo-degenerate WIMPs



- allows for coannihilation
- in the "nuclear range"

NB: "natural" EM or EW splitting of charged and neutral states

$\Delta m \sim \frac{\alpha}{\pi} m \sim 100$ MeV

[cf. Cirelli, Fornengo, Strumia '05]

- Type A: weak current $\mathcal{L}_{int} = g J^{\mu -}_{\chi_1 \chi_2} W^+_\mu + h.c.$
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$(N\chi_2^-)$	Z	E_b^{Gaussian} (MeV)	E_b^{Const} (MeV)
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$(^4\text{He}\chi_2^-)$	2	0.346	-
$(^{11}\text{B}\chi_2^-)$	5	2.24	2.13
$(^{12}\text{C}\chi_2^-)$	6	2.8	2.7
$(^{14}\text{N}\chi_2^-)$	7	3.5	3.2
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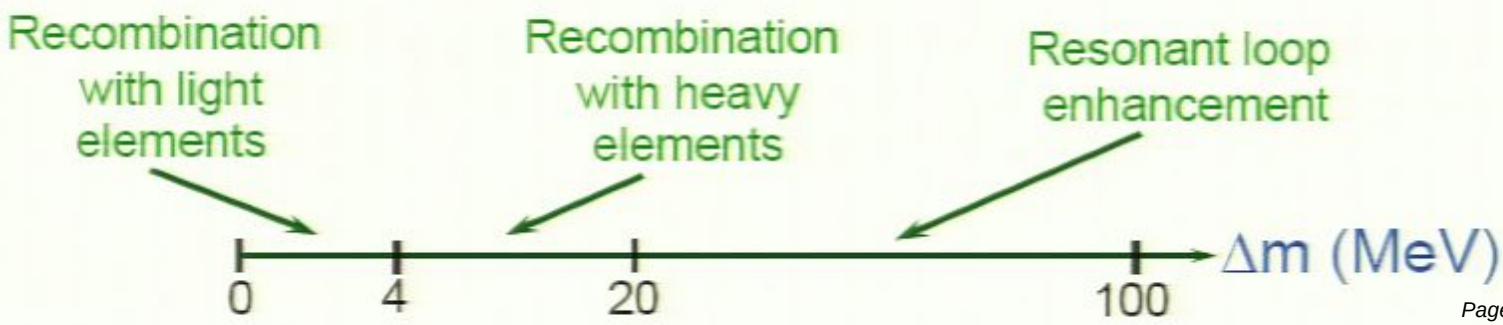

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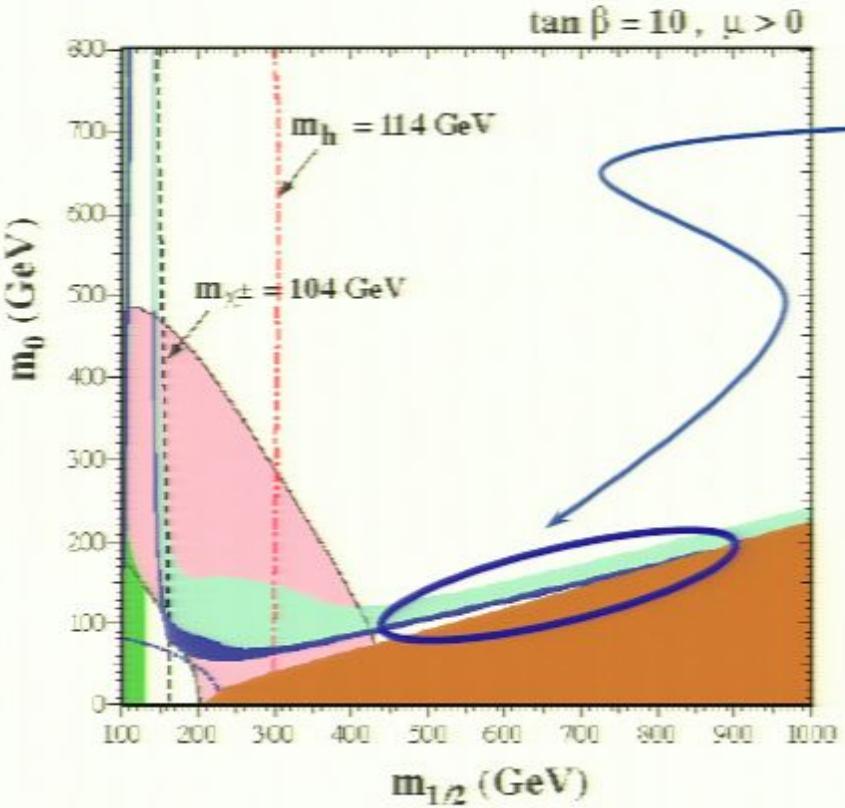

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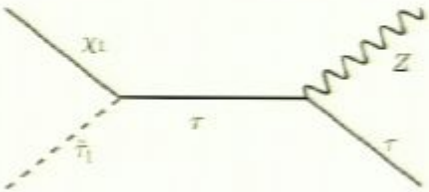

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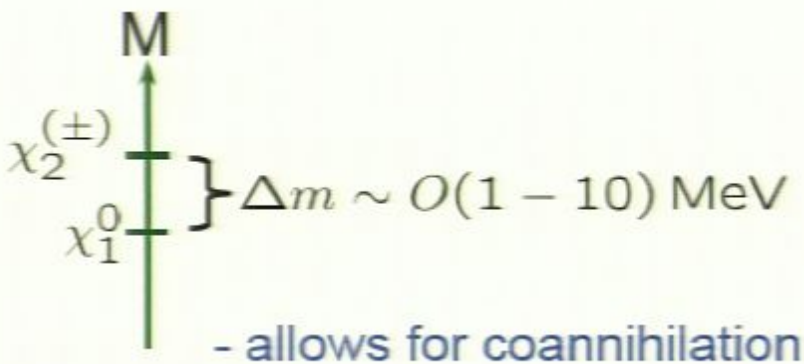

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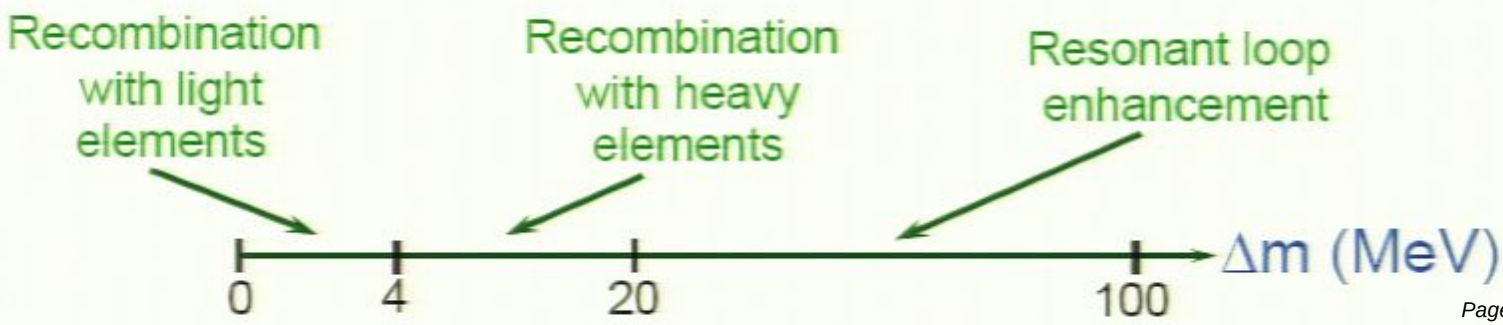
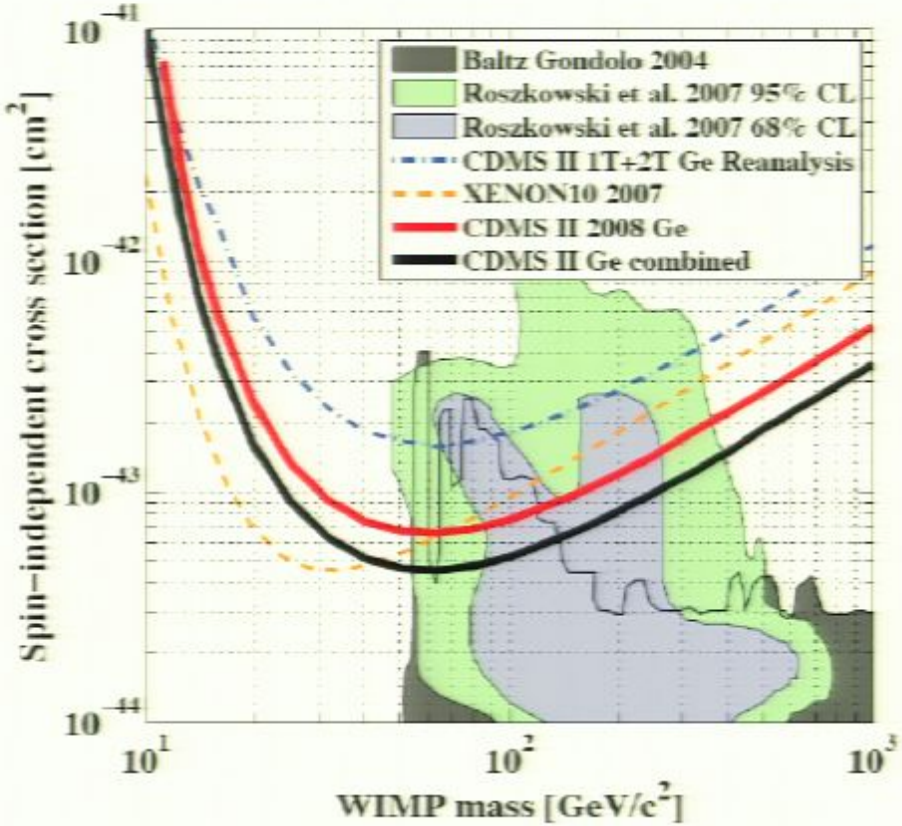


Direct Probes

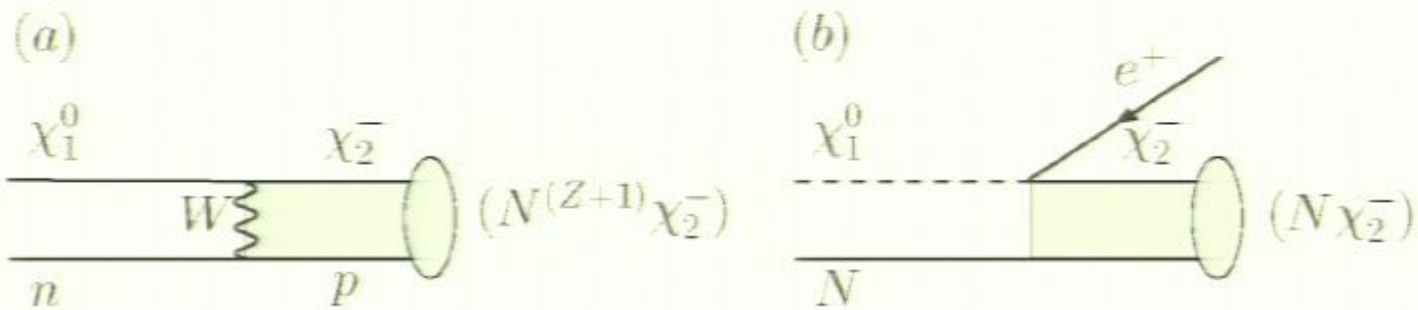
Existing limits test elastic scattering with10-100 keV nuclear recoil energy

$$\frac{1}{2}m_\chi v_\chi^2 \sim 50\ \text{keV}$$



[CDMS Collab. '08]

Direct probes - impact of recombination



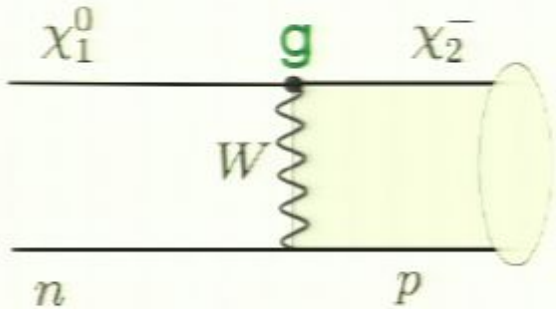
Crucial point: MeV-scale energy release

↓

Distinct signatures for direct detection experiments

Direct probes - CC recombination

Type A:



$$(N^{(Z+1)}\chi_2^-)^* \longrightarrow (N^{(Z+1)}\chi_2^-) + (\gamma, n, \ldots)$$

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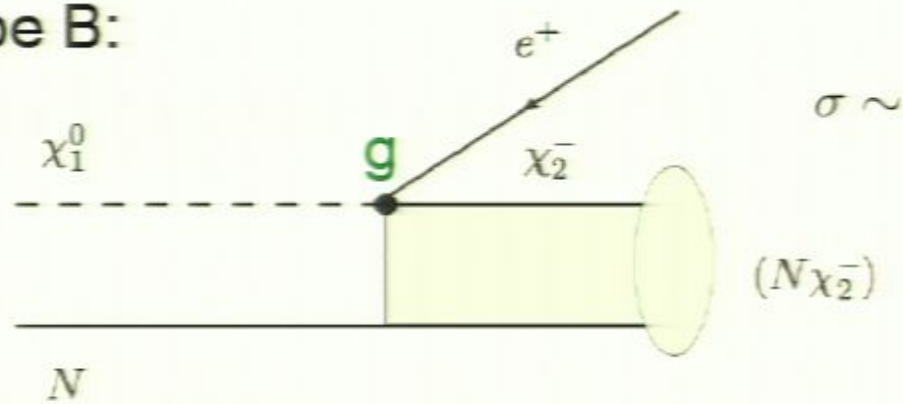
$$\langle \sigma_{\rm res} v \rangle \sim 10^{-38}\,{\rm cm}^2$$

Direct probes - EM recombination

Type B:



$$\sigma \sim \Gamma_{\chi_1 \to \chi_2} |\langle \psi_N^{\text{scat}} | \psi_N^{\text{bound}} \rangle| \times F_G$$

$$\langle \sigma_{\text{rec}} v \rangle \sim g^2 \frac{(E_e + m_e)|p_e|}{m_\chi} R_N^3 \left(\frac{a_B}{R_N} \right)^{3/4} \times F_G$$

$$\sigma_{p,n} \sim 10^{-39} \left(\frac{g^2}{4\pi\alpha_w} \right) \text{cm}^2$$

For heavy nuclei

Constraints from rare isotope searches

- No binding to H, He for $\Delta m > 0.5 MeV$
- Strongest constraints on B, C and O if $0.5 MeV < \Delta m < 4 MeV$

$$f_C < 10^{-20} \quad for \quad (N\chi_2^-)$$
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[Hemmick et al. '90]

$$\langle \sigma_{\rm rec} v \rangle|_{\rm max} < 10^{-43} {\rm cm}^2 \left(\frac{f_{\rm exp}}{10^{-20}}\right) \left(\frac{10^9 {\rm yr}}{\tau_{\rm exp}}\right)$$

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No significant constraint for $\Delta m > 5 MeV$!!

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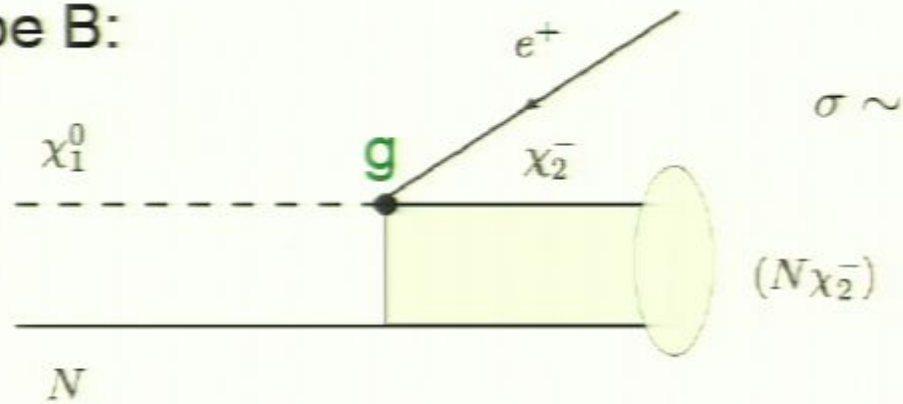

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Indirect Probes

- Gamma rays from annihilation e.g. in the Galactic center
- Positrons and the 511keV signal
- Neutrinos from annihilation e.g. in the sun

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This is highly suppressed for pseudo-degenerate WIMPs due to preferential capture by Fe (if $\Delta m<10$ MeV)

Indirect probes - Resonant Annihilation

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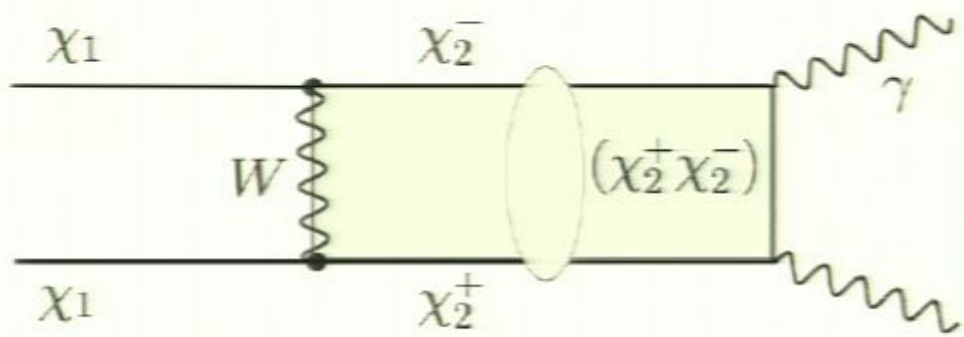


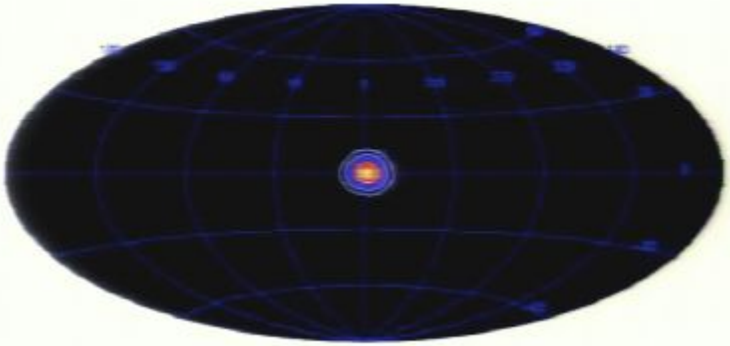
Enhanced mono-energetic gamma flux

$$\langle \sigma v \rangle \sim \frac{\Gamma_{2\gamma}}{(m_\chi T_{eff})^{3/2}} e^{-E_R/T_{eff}} \qquad T_{eff} \sim O(1MeV) \qquad E_R = 2\Delta m - \frac{1}{4} m_\chi \alpha^2$$

$$\langle \sigma v \rangle \sim 10^{-35} \left(e^{-E_R/(1MeV)} \right) cm^2$$

NB: less important for relic abundance as T_{eff} much larger

Indirect probes - Galactic 511 keV line



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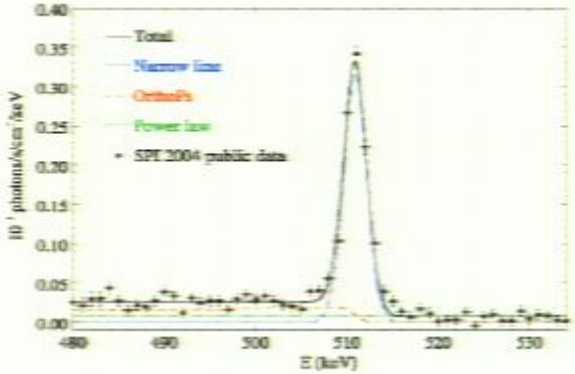

[INTEGRAL/SPI '03-'07]

Requires a low injected positron energy, so recombination of WIMPs with C,N,O nuclei in the ISM is a possibility…

$$\chi^0 + N \longrightarrow (\chi^- N) + e^+$$

[Pospelov & AR '07]

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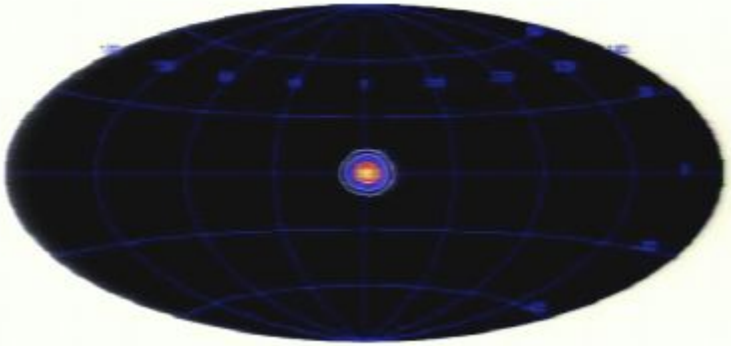

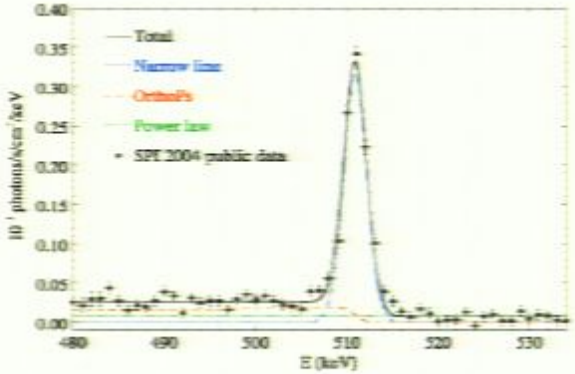

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✗ Large $\sigma_{\rm cap}$ (C,N,O) excluded by terrestrial isotopic bounds

An asymmetric distribution of positrons in the Galactic disk revealed by γ-rays

[Nature, Jan'08]

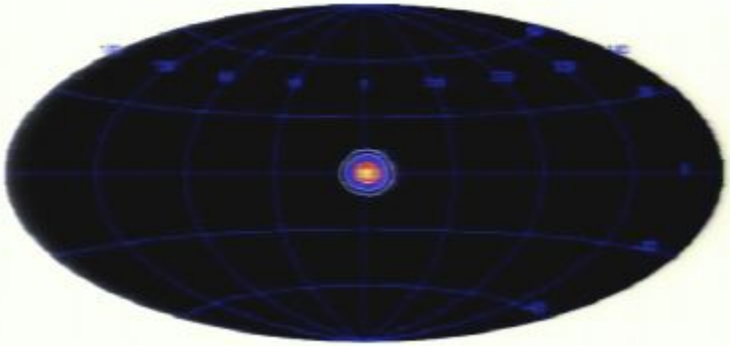
Georg Weidenspointner[1,2,3], Gerry Skinner[1,4,5], Pierre Jean[1], Jürgen Knödlseder[1], Peter von Ballmoos[1], Giovanni Bignami[1,6], Roland Diehl[7], Andrew W. Strong[8], Bertrand Cordier[9], Stéphane Schanne[9] & Christoph Winkler[7]

Summary

A dark matter sector with near-degeneracies e.g. between the WIMP and excited charged states can significantly modify the signatures for direct and indirect detection:

- For O(10 MeV) splitting, recombination processes may dominate the cross-section in direct detection experiments.
- Resonant annihilation may enhance galactic mono-energetic γ-ray signal
- Other (in)direct effects …?

Indirect probes - Galactic 511 keV line



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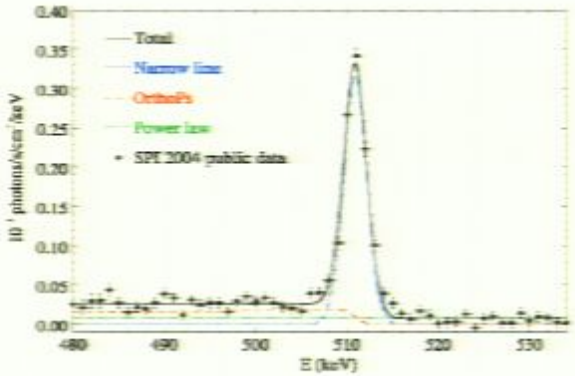

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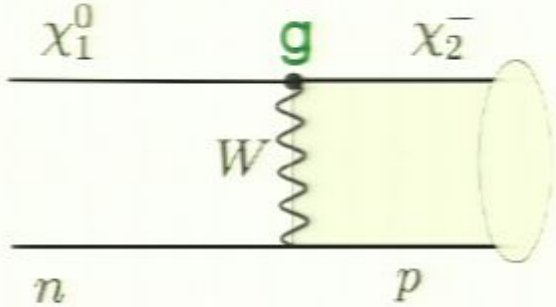

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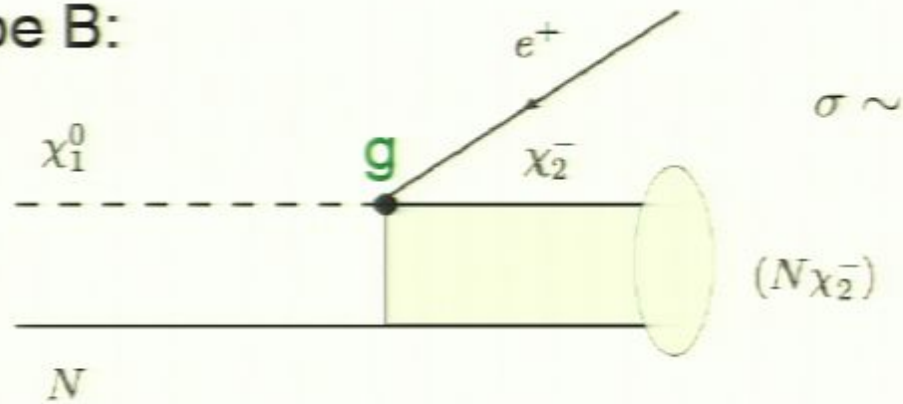

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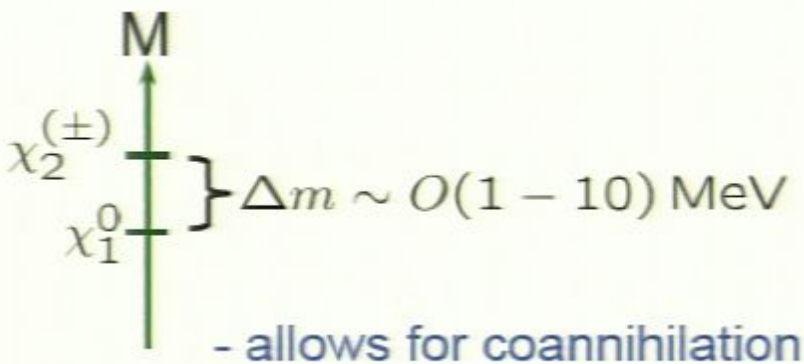

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