Light Singlino Dark Matter

Martin W. Winkler

In Collaboration with R. Kappl, M. Ratz

arXiv:1010.0553 (to appear in PLB)

PPSM Colloquium, Munich

December 10, 2010

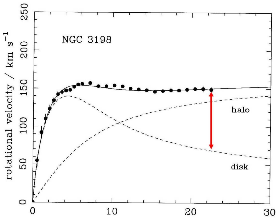
TECHNISCHE UNIVERSITÄT MÜNCHEN

Outline

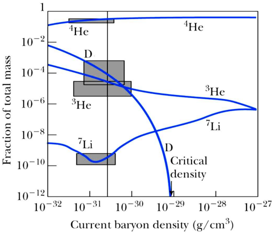
1. Dark Matter and Direct Detection
2. A Singlet Extension of the MSSM
3. Singlinos as Dark Matter
4. Experimental Prospects
5. Conclusion

Evidence for Dark Matter

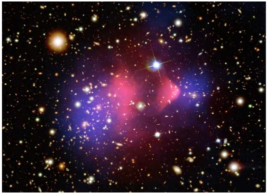
Galaxy rotation curves



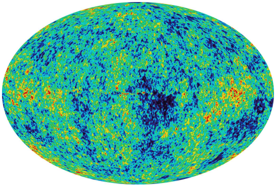
Big Bang Nucleosynthesis



Gravitational Lensing

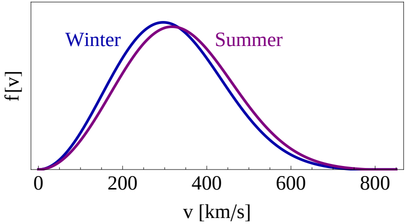


Cosmic Microwave Background



Properties of Dark Matter

- cold, (meta)stable, “dark”
- overall density: $\Omega_{\mathrm{DM}} \simeq 0.23$
  local density: $\rho_{\mathrm{loc}} \simeq 0.39\ \mathrm{GeV}/\mathrm{cm}^3$
  Catena et al., JCAP **08** (2010)
- local velocity distribution



Maxwellian distribution

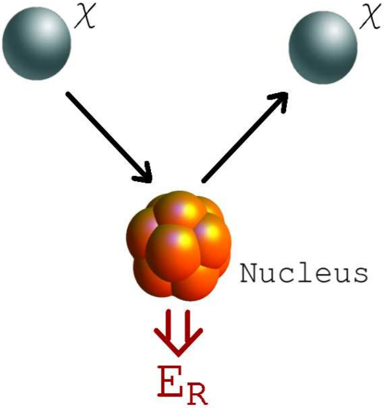
- leading candidate: WIMP

Direct Detection of WIMPs

- WIMP χ passes detector
  $\rightarrow$ liquid noble gas (Xenon...)
  $\rightarrow$ crystal (CRESST...)
- scatters off target nucleus
- $E_R \rightsquigarrow$ Light, Heat

$\big\downarrow$

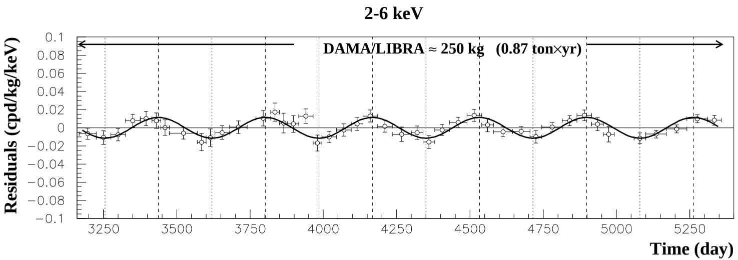
detector signal



Results I

- null results by Xenon, CDMS, Zeplin, Edelweiss
- modulation signal at DAMA

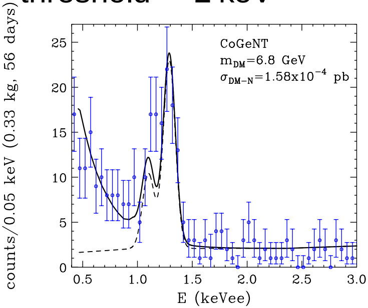
Bernabei et al., Eur. Phys. J. **C67** (2010)



- scintillation light in NaI detector
- 1.17 t yr exposure (13 yrs), 8.9 σ significance of signal
- amplitude, period, phase of signal consistent with WIMPs

Results II

- CoGeNT: germanium detector with very low threshold $\sim$ 2 keV

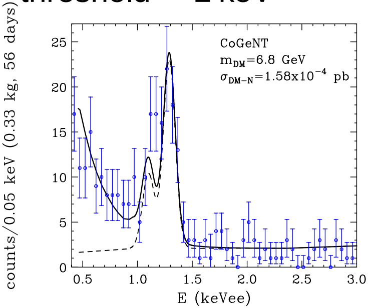


Aalseth et al., **arXiv:1002.4703** [astro-ph] (2010),
Hooper et al., **arXiv:1007.1005** [hep-ph] (2010)

- exponential rise of events at low energies
- claim: not explainable by electronic noise

Results II

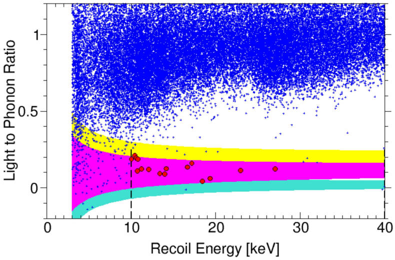
- CoGeNT: germanium detector with very low threshold $\sim$ 2 keV



Aalseth et al., **arXiv:1002.4703** [astro-ph] (2010), Hooper et al., **arXiv:1007.1005** [hep-ph] (2010)

- exponential rise of events at low energies
- claim: not explainable by electronic noise

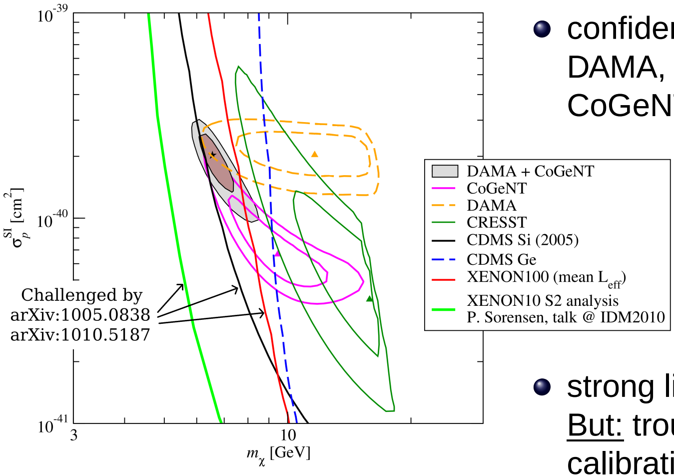
- CRESST: cryogenic $CaWO_4$ detector



Talks by Seidel and Schwetz at **IDM 2010**

- 32 events in the oxygen band ($\sim$400 kg d exposure)
- background estimate by CRESST: $\sim$9 events

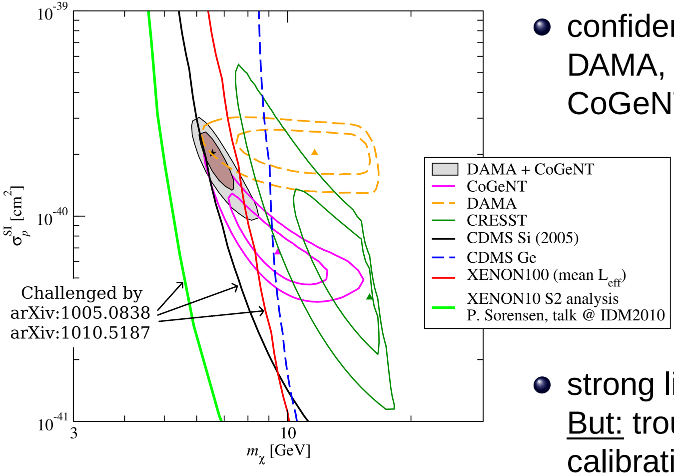
Confidence Regions and Exclusion Curves



from T. Schwetz (talk at IDM 2010)

- confidence regions of DAMA, CRESST and CoGeNT rather close
- strong limits
  <u>But:</u> trouble with energy calibration

Confidence Regions and Exclusion Curves



from T. Schwetz (talk at IDM 2010)

- confidence regions of DAMA, CRESST and CoGeNT rather close
- strong limits
  But: trouble with energy calibration

light WIMPs $m_\chi \simeq 5 - 10$ GeV, $\sigma_p \sim 10^{-40}$ cm^2 could explain DAMA, CoGeNT and CRESST !

Candidates for Light WIMPs

- Standard Model:
  - neutrino

Candidates for Light WIMPs

- Standard Model:
  - ~~neutrino~~ hot dark matter, mass too small

Candidates for Light WIMPs

- Standard Model:
  - ~~neutrino~~ hot dark matter, mass too small
- Minimal Supersymmetric Standard Model:
  - sneutrino
  - wino, higgsino
  - bino

Candidates for Light WIMPs

- Standard Model:
  - ~~neutrino~~ hot dark matter, mass too small
- Minimal Supersymmetric Standard Model:
  - ~~sneutrino~~ Z width
  - wino, higgsino
  - bino

Candidates for Light WIMPs

- Standard Model:
  - ~~neutrino~~ hot dark matter, mass too small
- Minimal Supersymmetric Standard Model:
  - ~~sneutrino~~ Z width
  - ~~wino, higgsino~~ collider searches
  - bino

Candidates for Light WIMPs

- Standard Model:
  - ~~neutrino~~ hot dark matter, mass too small
- Minimal Supersymmetric Standard Model:
  - ~~sneutrino~~ Z width
  - ~~wino, higgsino~~ collider searches
  - ~~bino~~ cross section too small

Candidates for Light WIMPs

- Standard Model:
  - ~~neutrino~~ hot dark matter, mass too small
- Minimal Supersymmetric Standard Model:
  - ~~sneutrino~~ Z width
  - ~~wino, higgsino~~ collider searches
  - ~~bino~~ cross section too small
  - mixture bino higgsino?

  σ_p maximal at very large $\tan\beta$, $m_H \simeq 100$ GeV, $\cos\alpha = 1$:
  Belikov et al., **arXiv:1009.0549** [hep-ph] (2010)

$$\sigma_p \sim 10^{-41}\,\text{cm}^2 \times \frac{N_{13}^2}{0.1} \qquad \text{but} \quad N_{13}^2 \lesssim 0.1$$

Candidates for Light WIMPs

- Standard Model:
  - ~~neutrino~~ hot dark matter, mass too small
- Minimal Supersymmetric Standard Model:
  - ~~sneutrino~~ Z width
  - ~~wino, higgsino~~ collider searches
  - ~~bino~~ cross section too small
  - ~~mixture bino higgsino?~~

  σ_p maximal at very large $\tan\beta$, $m_H \simeq 100$ GeV, $\cos\alpha = 1$:

  Belikov et al., **arXiv:1009.0549** [hep-ph] (2010)

$$\sigma_p \sim 10^{-41}\,\mathrm{cm}^2 \times \frac{N_{13}^2}{0.1} \qquad \text{but} \quad N_{13}^2 \lesssim 0.1$$

A Supersymmetric Model

- introduce one singlet superfield S
- new particles: singlino $\widetilde{s}$, singlet scalar h_s, pseudoscalar a_s
- most general superpotential (including S^2-term)

  Drees, Int. J. Mod. Phys. **A4** (1989)

$$\mathcal{W} \;=\; \mathcal{W}_{\text{MSSM}} + \lambda\, S\, H_u H_d + \frac{\mu_s}{2}\, S^2 + \frac{\kappa}{3}\, S^3$$

- $+$ corresponding soft terms
- interaction between singlet and MSSM controlled by λ
- interaction in singlet sector controlled by κ

Keeping Singlets Light

$\underline{\lambda = 0}$

- MSSM and singlet sector decouple
- assumption: (singlet mass terms) $\sim M_{\text{singlet}} \sim 10$ GeV

  $\Rightarrow m_{h_s} \sim m_{a_s} \sim m_{\tilde{s}} \sim 10$ GeV
- light $\tilde{s}$ LSP, but vanishing σ_p

$\underline{\lambda = 10^{-2} \ldots 10^{-3}}$

- s receives vacuum expectation value $\langle s \rangle \sim v$
- new singlet mass terms like $\kappa \langle s \rangle$

$\Rightarrow$ singlets stay light if $\kappa \lesssim 0.1$

Mixing with MSSM Fields

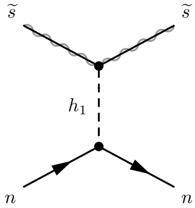
- apply MSSM decoupling limit
  - ignore heavy MSSM Higgs
  - light MSSM Higgs h Standard Model like
- $\widetilde{s}$, a_s : (almost) pure singlets
- h_s mixes slightly with SM Higgs

$$h_1 = \cos\theta\, h_s - \sin\theta\, h \quad \text{with } \sin\theta \sim 0.01$$

h_1 mimics light SM Higgs with suppressed couplings

Can Singlinos explain CRESST, . . . ?

- correct mass range (by assumption)
- WIMP nucleon cross section dominated by h_1-exchange

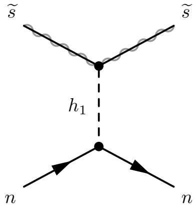


- suppressed by $\sin^2\theta$
- but: enhanced by $1/m_{h_1}^4$

$$\sigma_p \sim 10^{-40}\,\mathrm{cm}^2 \left(\frac{\kappa}{0.08}\right)^2 \left(\frac{\sin\theta}{0.03}\right)^2 \left(\frac{4\,\mathrm{GeV}}{m_{h_1}}\right)^4$$

Can Singlinos explain CRESST, . . . ?

- correct mass range (by assumption)
- WIMP nucleon cross section dominated by h_1-exchange



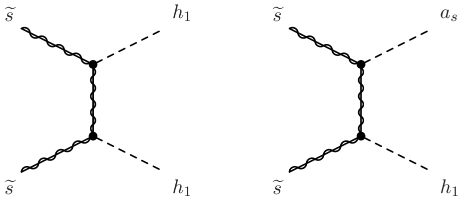
- suppressed by $\sin^2\theta$
- but: enhanced by $1/m_{h_1}^4$

$$\sigma_p \sim 10^{-40}\,\mathrm{cm}^2 \left(\frac{\kappa}{0.08}\right)^2 \left(\frac{\sin\theta}{0.03}\right)^2 \left(\frac{4\,\mathrm{GeV}}{m_{h_1}}\right)^4$$

$\Rightarrow$ CRESST, . . . explanation for sizeable κ, small m_{h_1}

Singlinos as Thermal Relics

- singlinos thermally produced in the early universe
- for thermal relic $\boldsymbol{\Omega} \propto \langle \sigma v_{\text{rel}} \rangle^{-1}$
- sizeable κ, small m_{h_1} opens annihilation channel(s)



$$\sigma v_{\text{rel}} \sim \mathcal{O}(1)\,\frac{\kappa^4}{16\,\pi}\,\frac{1}{m_{\widetilde{s}}^2} \times \begin{cases} v_{\text{rel}}^2 & (h_1 h_1\text{-channel}) \\ 1 & (h_1 a_s\text{-channel}) \end{cases}$$

- $\boldsymbol{\Omega}_{\widetilde{s}} = \boldsymbol{\Omega}_{\text{DM}}$ for $\kappa = 0.01 \ldots 0.1$

A Benchmark Scenario

Input Parameters

Quantity	Value
μ	370 GeV
$\langle s \rangle$	163 GeV
A_κ	-9 GeV
μ_s	-19 GeV
$B\mu_s$	0
λ	-0.003
κ	0.08

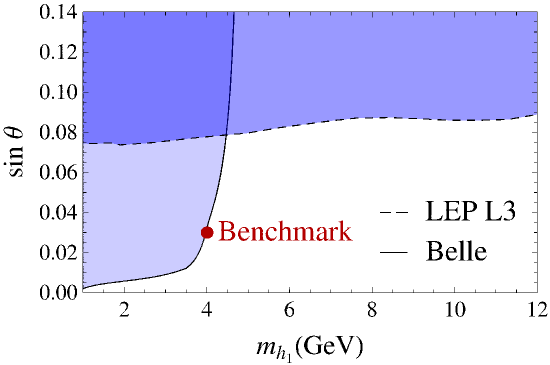
Predictions

Quantity	Value
m_{a_s}	28 GeV
$m_{\tilde{s}}$	7 GeV
m_{h_1}	4 GeV
$\sin\theta$	0.03
σ_p	$\sim 10^{-40}$ cm^2
$\boldsymbol{\Omega} h^2$	~ 0.1

- $m_{\tilde{s}}$, σ_p to explain CoGeNT, DAMA, CRESST
- $\boldsymbol{\Omega}_{\tilde{s}} = \boldsymbol{\Omega}_{\text{DM}}$ through annihilation into $h_1\, h_1$
- OK with experimental constraints ?

Experimental Constraints on Light Scalar

- LEP searches for Higgs-like scalars
- h_1 can be produced in Meson decays (e.g. BELLE)



- can be translated into limits on $\sin\theta$
- benchmark point viable

Experimental Prospects

Direct Detection:

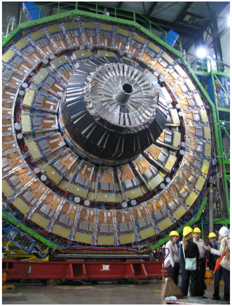
- light Dark Matter interpretation will be tested by COUPP, ANAIS,..., new runs of CRESST, CoGeNT

B Factories:

- light scalar h_1 can be detected in B or Υ-meson decays

Large Hadron Collider:

- search for signals of singlino LSPs
- some promising signatures
  - many leptons
  - displaced vertices for Bino NLSP
  - charged tracks for stau NLSP



Conclusion

- several DM direct detection experiments hint at light WIMPs with rather large cross sections

Conclusion

- several DM direct detection experiments hint at light WIMPs with rather large cross sections
- neither the SM nor the MSSM can account for such WIMPs

Conclusion

- several DM direct detection experiments hint at light WIMPs with rather large cross sections
- neither the SM nor the MSSM can account for such WIMPs
- a simple singlet extension of the MSSM offers a candidate: the singlino

Conclusion

- several DM direct detection experiments hint at light WIMPs with rather large cross sections
- neither the SM nor the MSSM can account for such WIMPs
- a simple singlet extension of the MSSM offers a candidate: the singlino
- accompanied by scalar which mixes with SM Higgs

Conclusion

- several DM direct detection experiments hint at light WIMPs with rather large cross sections
- neither the SM nor the MSSM can account for such WIMPs
- a simple singlet extension of the MSSM offers a candidate: the singlino
- accompanied by scalar which mixes with SM Higgs
- singlino nucleon interactions mediated by this scalar explain direct detection signals

Conclusion

- several DM direct detection experiments hint at light WIMPs with rather large cross sections
- neither the SM nor the MSSM can account for such WIMPs
- a simple singlet extension of the MSSM offers a candidate: the singlino
- accompanied by scalar which mixes with SM Higgs
- singlino nucleon interactions mediated by this scalar explain direct detection signals
- correct relic density obtained by annihilation of singlinos into scalars

Conclusion

- several DM direct detection experiments hint at light WIMPs with rather large cross sections
- neither the SM nor the MSSM can account for such WIMPs
- a simple singlet extension of the MSSM offers a candidate: the singlino
- accompanied by scalar which mixes with SM Higgs
- singlino nucleon interactions mediated by this scalar explain direct detection signals
- correct relic density obtained by annihilation of singlinos into scalars
- ingredients of this scenario will soon be tested by various experiments