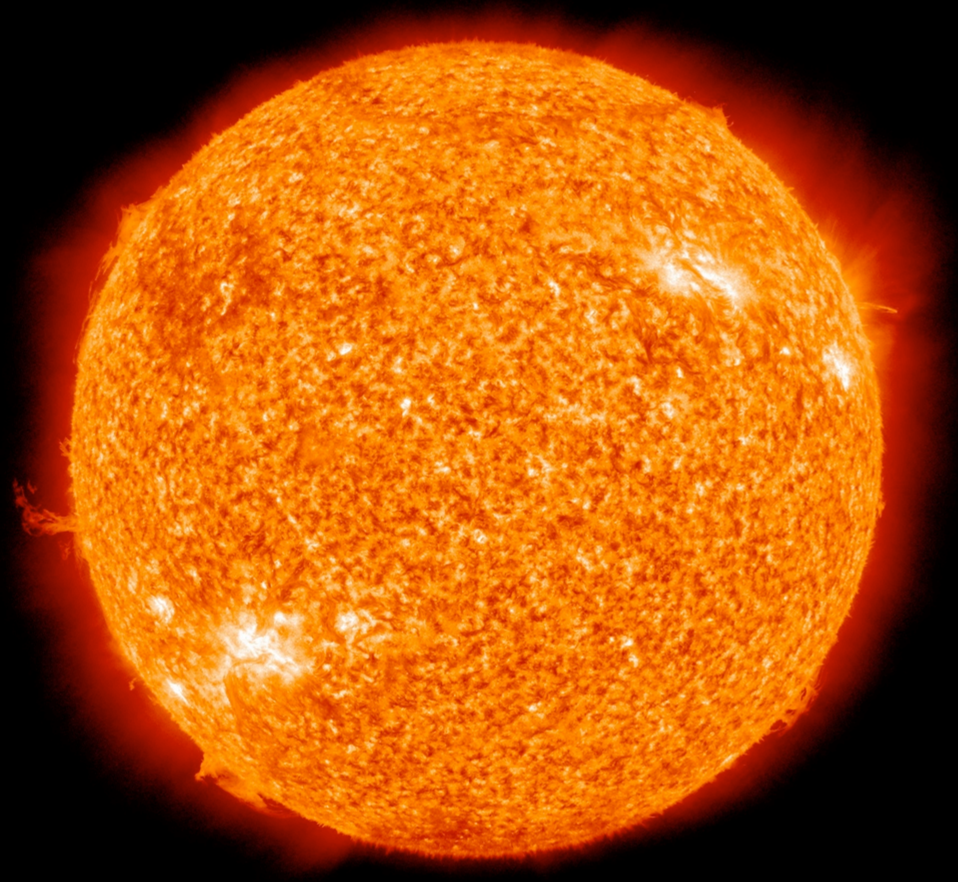
# Light Dark Matter and Neutrinos from the Sun



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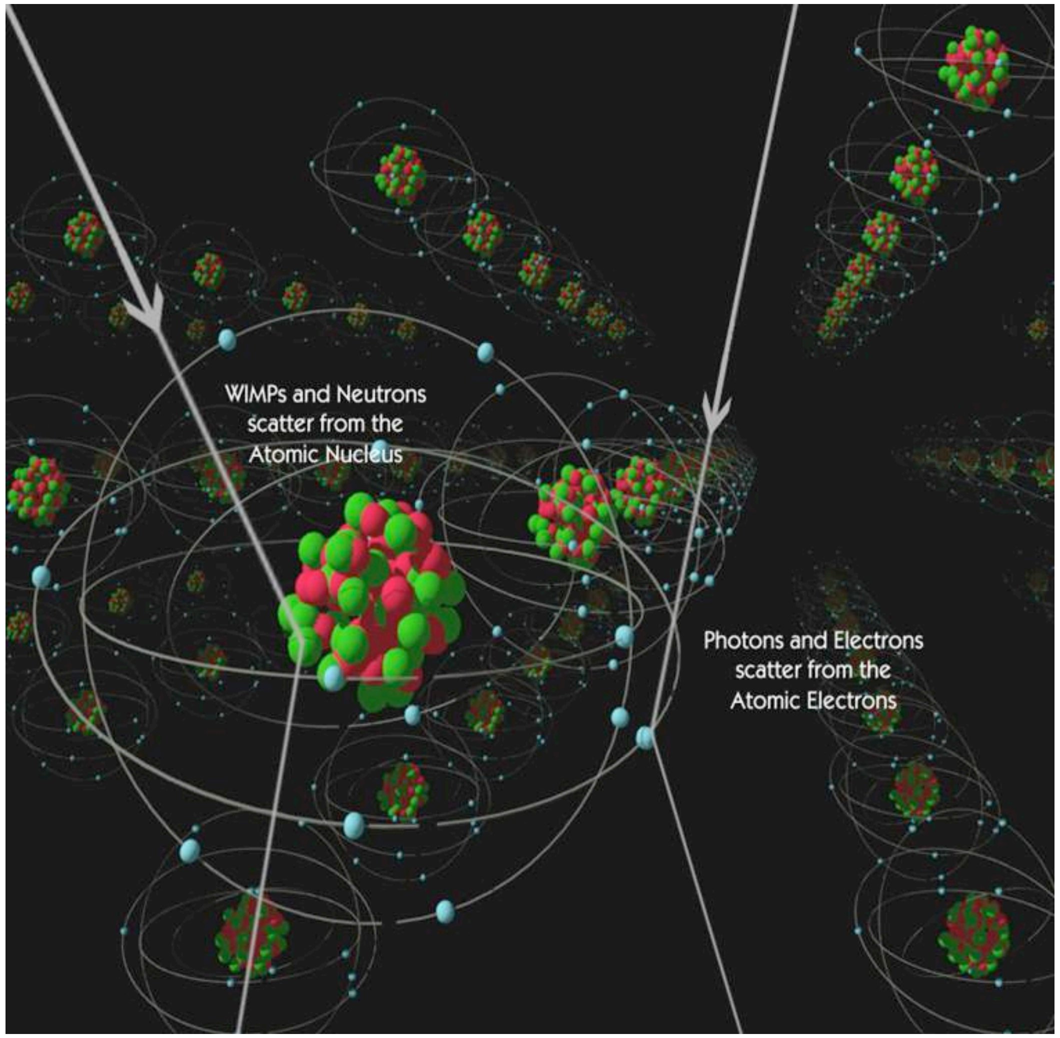
*in collaboration with*
*Rolf Kappl and Martin W. Winkler*

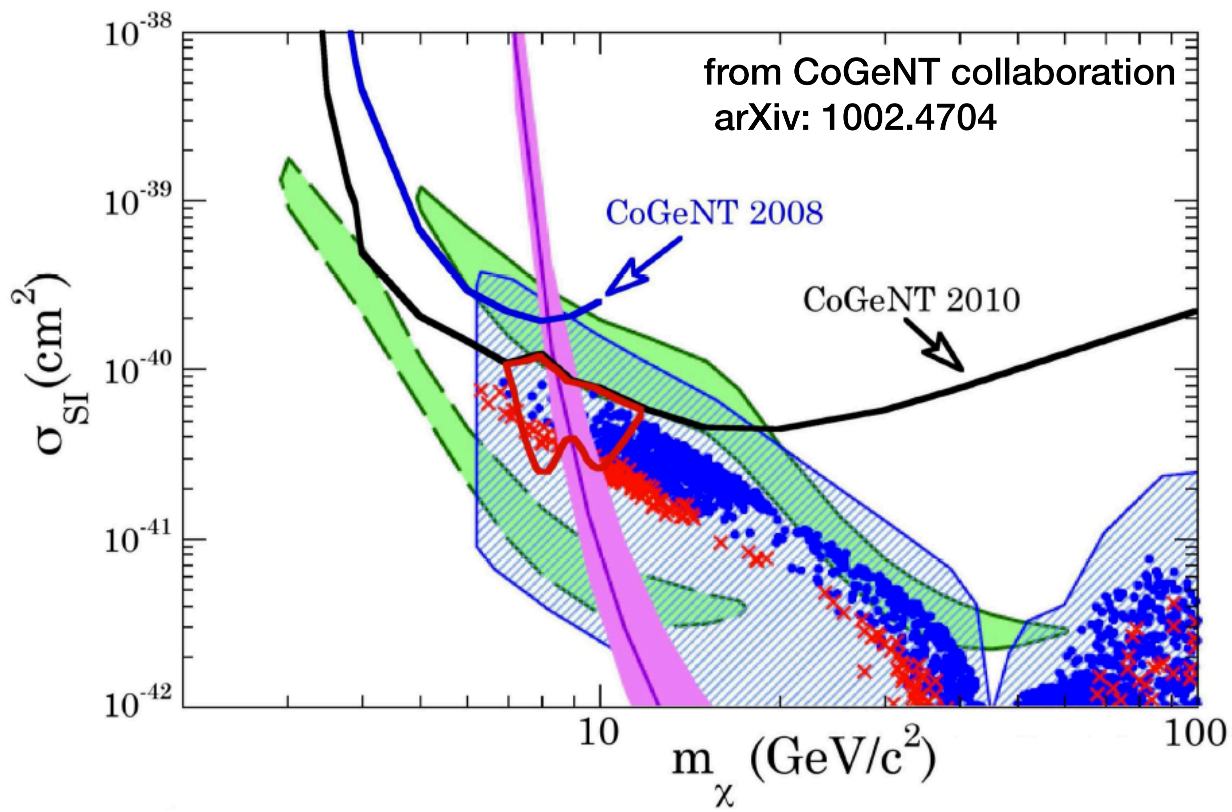
# Dark Matter direct detection




**Detection techniques:**

- ionization
- heat
- scintillation

# A direct detection of Dark Matter?




## CoGeNT

- rise in spectrum at low energies
- background? no satisfactory explanation

## CDMS

- 2 events survive all discrimination and subtraction procedures

## DAMA/Libra

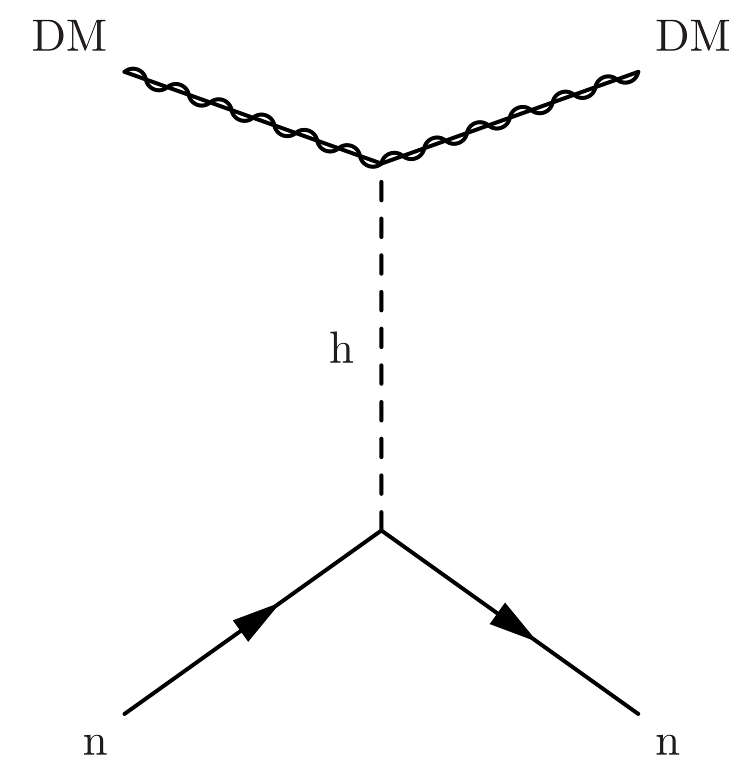
- observe annual modulation
- channeling effect? different mass/cross section ranges

WIMPs with m ~ 5 - 10 GeV and $\sigma_n \sim 10^{-40}$ cm$^2$ could fit all these signals.

# Which SUSY models accomodate such WIMPs?

**MSSM**: Higgs known to be heavy
⇒ cross section suppressed

**Solution: singlet-extended SUSY models allow for lighter Higgs bosons as intermediate particles!**




N.B.: There is also a recent paper where a complex singlet is added to SM (CSM). They can also explain these signals.
*Barger, Gao, McCaskey, Shaughnessy '10*

# Singlet-extended SUSY models

MSSM + gauge singlet superfield S

$$W = \mu H_u H_d + \lambda S H_u H_d + \frac{\mu_s}{2} S^2 + \frac{\kappa}{3} S^3 + \text{Yukawa}$$

NMSSM: $Z_3$ symmetry $\longrightarrow$ solution to $\mu$ - problem

S-MSSM: allow all terms $\longrightarrow$ no solution to $\mu$ - problem

New particles: CP-even and CP-odd scalar $h_s$ and $a_s$ , singlino $\tilde{s}$

Decoupling limit of MSSM Higgs sector: mixing only with light MSSM Higgs:

Two mass eigenstates:

$h_1$ mainly singlet $\qquad$ $h_2$ $\sim$ light MSSM Higgs

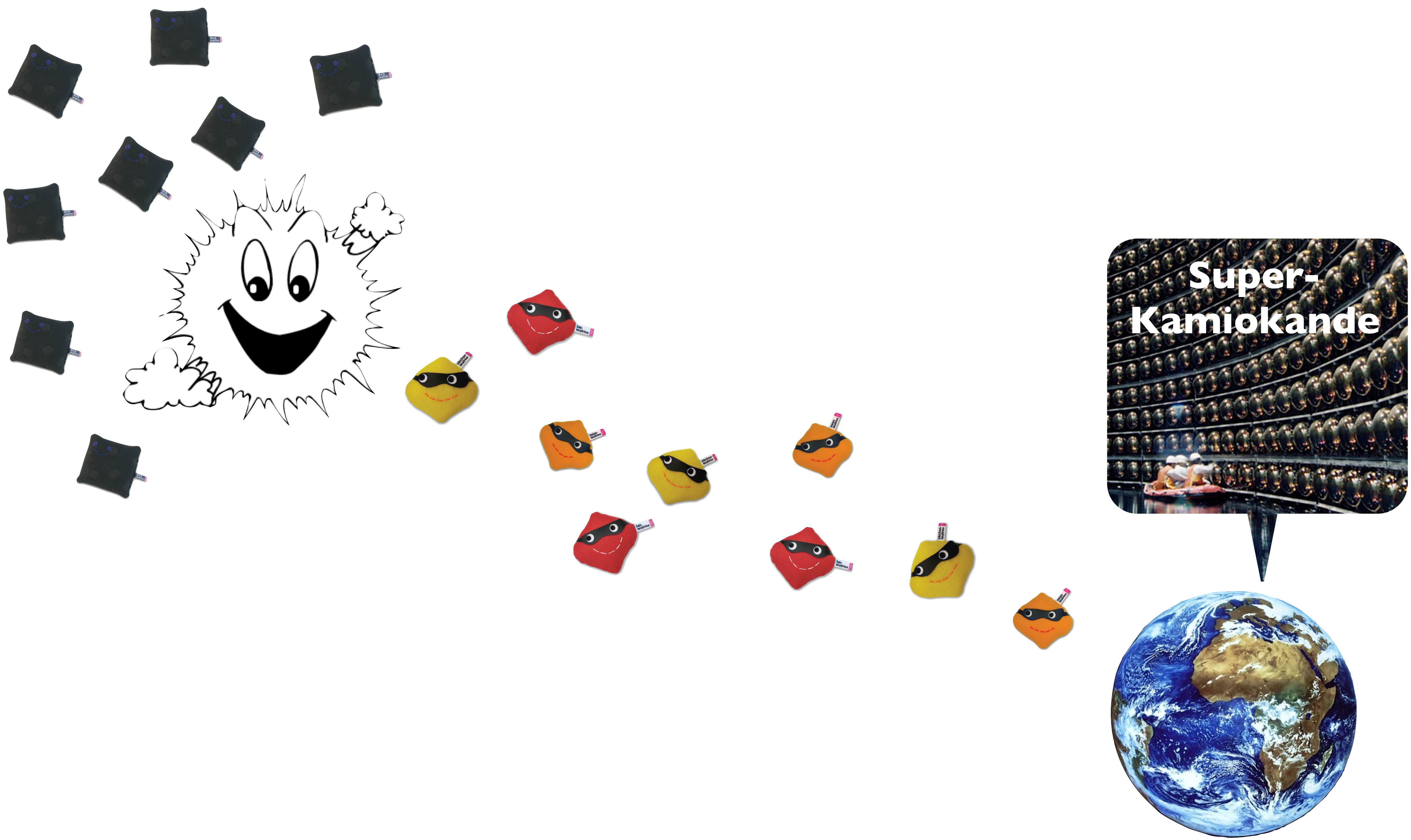
# Can singlet-extended SUSY models explain CoGeNT/ DAMA?

NMSSM: lightest neutralino mostly bino → small coupling to singlet like Higgs → cross section to small

S-MSSM: singlino DM with low mass & correct cross section thanks to mediation by light mainly singlet Higgs

Kappl, Ratz, Winkler '10
Belikov, Gunion, Hooper, Tait '10

# Do we expect other signals from light singlino DM?

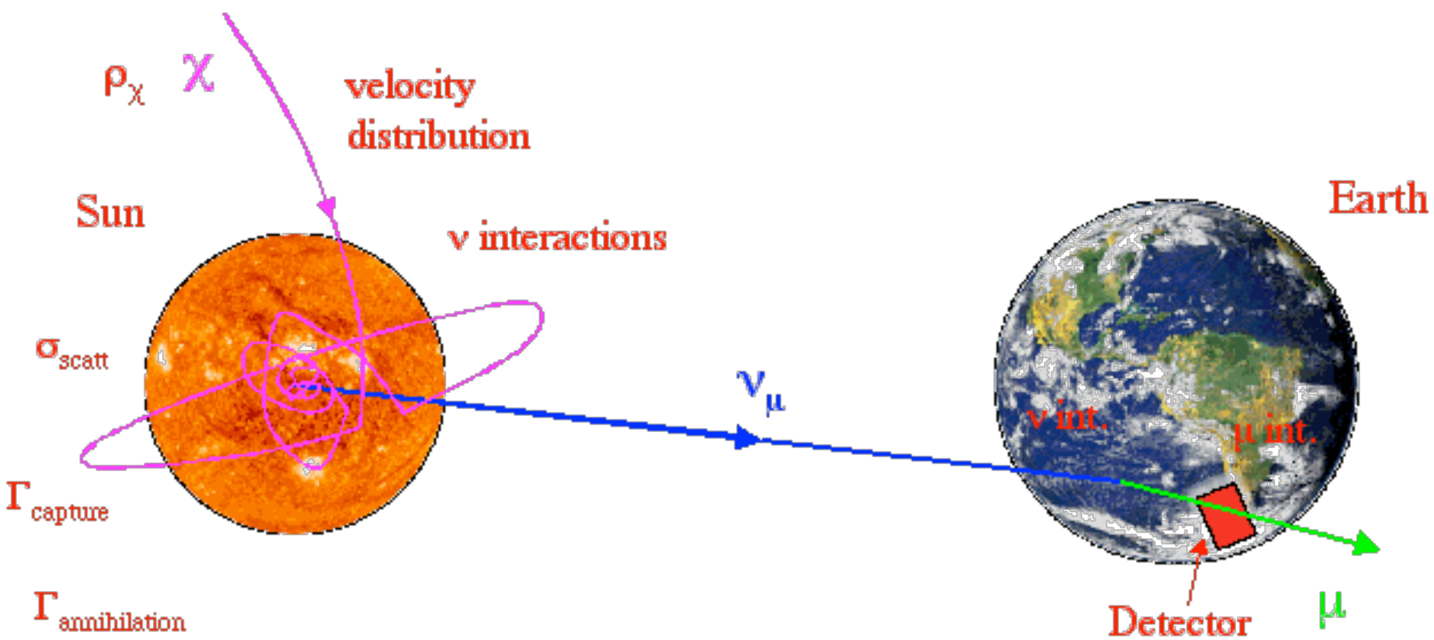


# Dark Matter capture and annihilation in the Sun

DM is captured inside Sun ↔ annihilations deplete DM population

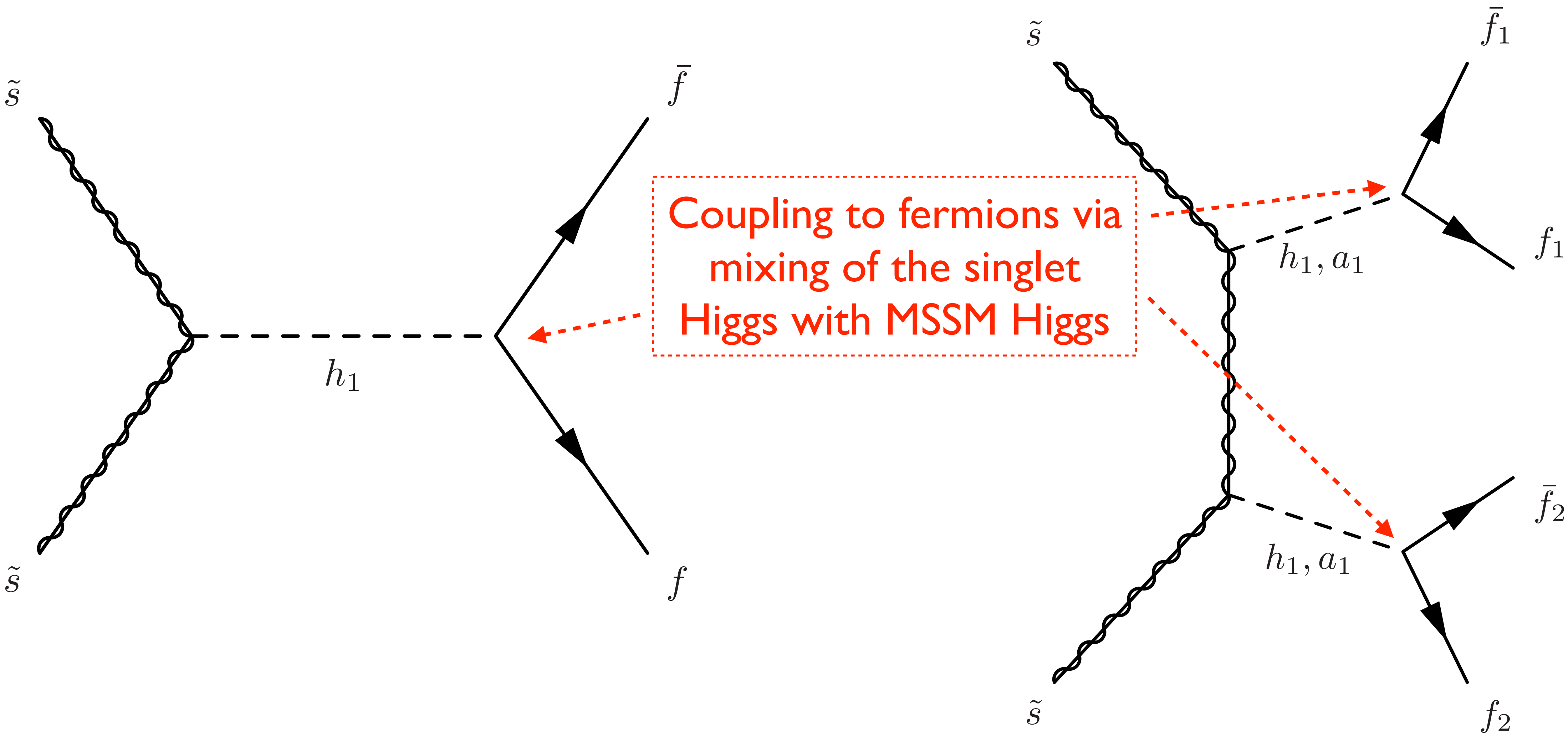
$$\Gamma_{\text{ann.}} = \frac{\Gamma_{\text{capt.}}}{2} \tanh^2(t_0/\tau_A)$$

Capture/annihilation equilibrium is reached: $\Gamma_{\text{ann.}} = \frac{\Gamma_{\text{capt.}}}{2}$




$$\Gamma_{\text{capt.}} \propto \sigma_n \rho_{\text{DM}} \left(\frac{1}{m_{\text{DM}}}\right)^2$$

# Annihilations of singlino Dark Matter




- Hadronization of quarks and lepton decay simulated with Pythia
- Free decay only if $\gamma\tau_{\rm dec.} < \tau_{\rm stop}$

# Neutrino propagation: oscillations, scatterings...

Cirelli, Fornengo, Montaruli, Sokalski, Strumia, Vissani '05
Blennow, Edsjö, Ohlsson '07

$$\frac{\mathrm{d}\rho}{\mathrm{d}r} = -i\,[H,\rho] + \left.\frac{\mathrm{d}\rho}{\mathrm{d}r}\right|_{\mathrm{CC}} + \left.\frac{\mathrm{d}\rho}{\mathrm{d}r}\right|_{\mathrm{NC}} + \left.\frac{\mathrm{d}\rho}{\mathrm{d}r}\right|_{\mathrm{injected}}$$

oscillations

scatterings only relevant for $E_\nu \gtrsim 100$ GeV

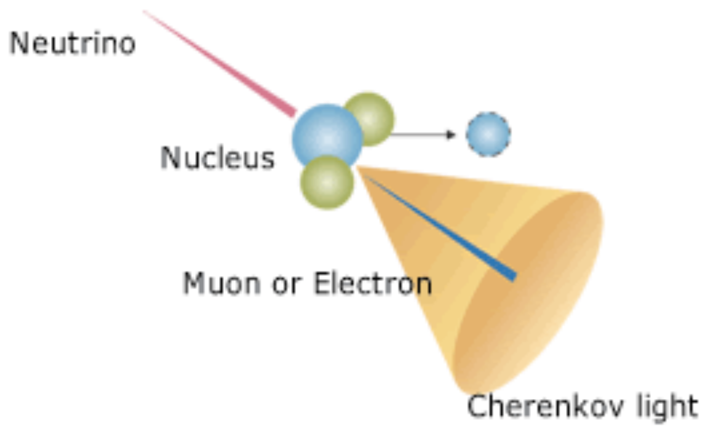
injected spectrum

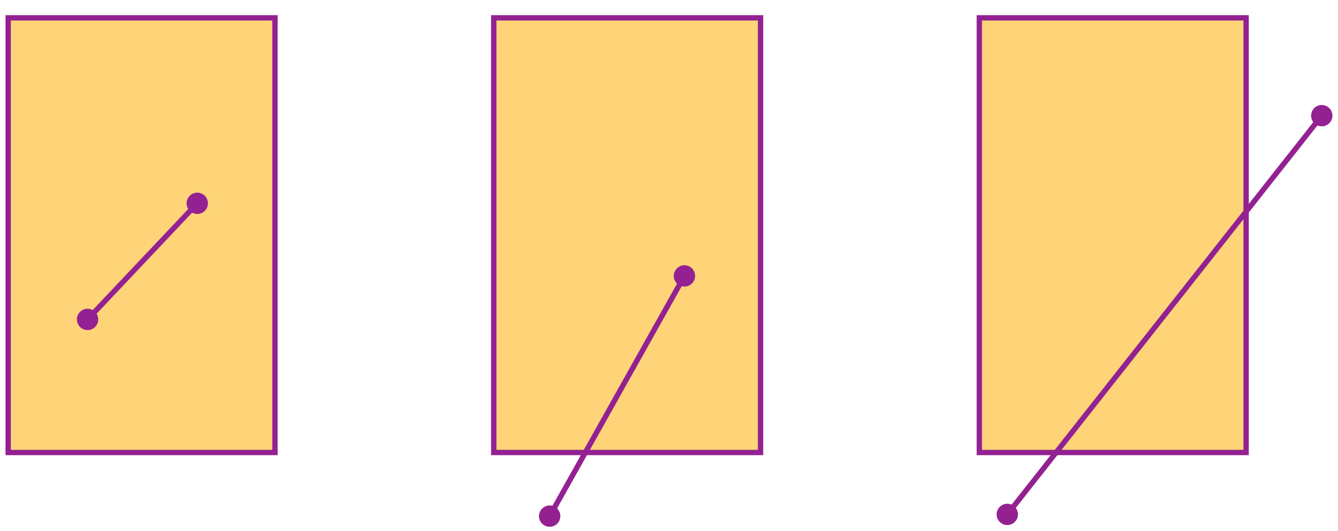
$$H = \frac{m^\dagger m}{2E_\nu} + \sqrt{2}G_F N_e \mathrm{diag.}(1,0,0)$$

Oscillations are averaged by:

- ☆ large variation in baseline
- ☆ finite energy resolution of detector

# Detection of neutrinos at Superkamiokande

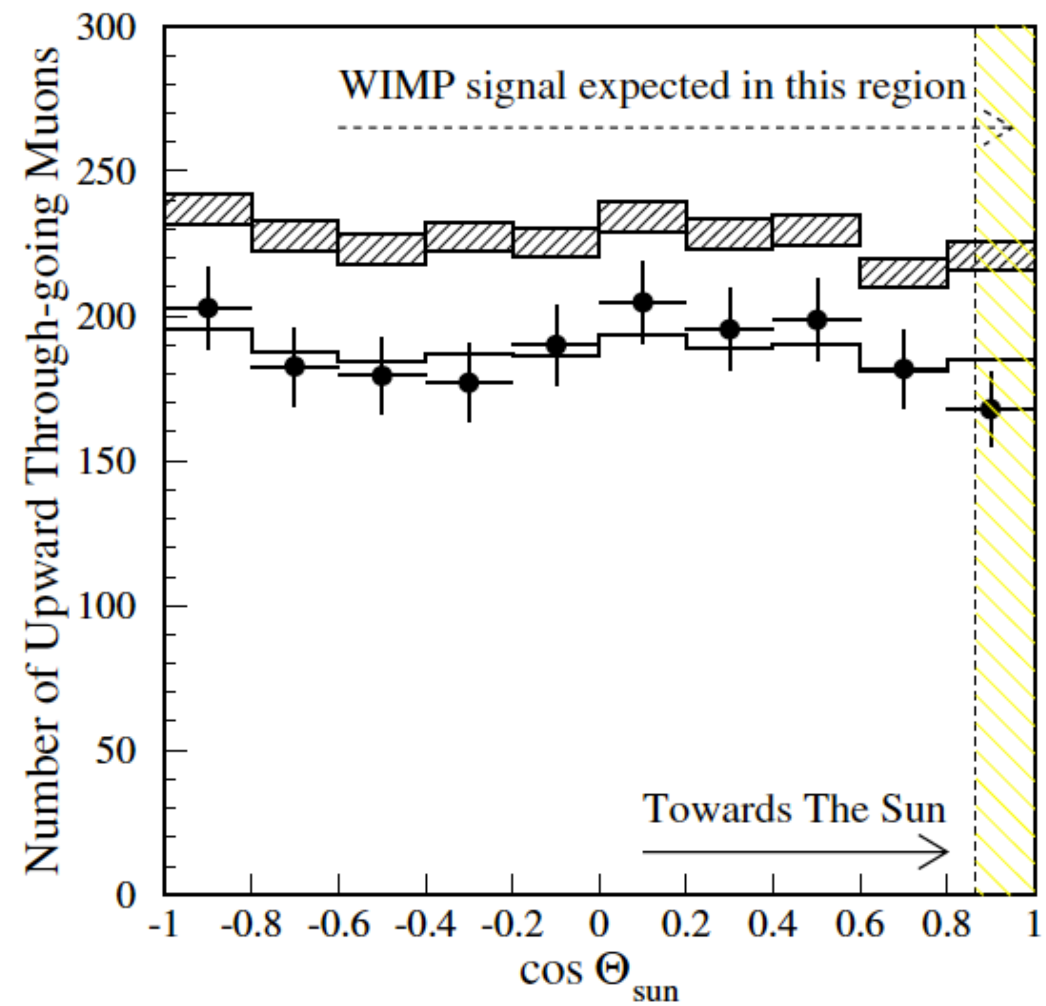


Fully-contained

Partially-contained

up-ward through-going



# Conclusions

- Direct detection of DM? If, yes: light DM with relatively large scattering cross section
- Possible in singlet extended MSSM
- Possible signal: neutrinos generated in DM annihilations inside Sun:
  - Accumulation of DM inside Sun
  - Annihilation + showering
  - Propagation of neutrinos to the Earth: oscillations
  - Detection of neutrinos in Super-Kamiokande

# Neutrino propagation for tri-bi-maximal mixing

Lehnert, Weiler '08

$\theta_{13} = 0$

$$H' = \begin{pmatrix} H_{2\times 2} & & 0 \\ & & 0 \\ 0 & 0 & \frac{\Delta m_{32}^2}{2E_\nu} \end{pmatrix}$$

$$|3\rangle_m = |3\rangle = \sum_\alpha U_{\alpha 3}^* |\alpha\rangle = \sin\theta_{23}|\mu\rangle + \cos\theta_{23}|\tau\rangle$$

10 MeV ~10 GeV

**adiabatic approximation**:

mass eigenstates in matter ≈ instantaneous eigenstates that diagonalize $H_{2x2}$ at point r, no level crossings

Centre of the Sun: $|1,0\rangle \simeq |e\rangle\,,\ |2,0\rangle = \cos\theta_{23}|\mu\rangle - \sin\theta_{23}|\tau\rangle$

$$\rho(0) = w_e |e\rangle\langle e| + w_\mu |\mu\rangle\langle\mu| + w_\tau |\tau\rangle\langle\tau|\,.$$

Off-diagonal elements acquire phase factor $\exp\left(-i\Delta m_{kj}^2 L/2E_\nu\right)$

→ averages to zero → drop off-diagonal elements

Evolution through the sun: $|1,0\rangle \to |2\rangle\,,\ |2,0\rangle \to |1\rangle\,,\ |3,0\rangle \to |3\rangle$

$$P_{\nu_\odot\to\nu_\beta} = \langle\beta|\rho(r > R_\odot)|\beta\rangle = w_e |U_{\beta 2}|^2 + \frac{1}{2}(w_\mu + w_\tau)\left(1 - |U_{\beta 2}|^2\right)$$

Tribimaximal mixing: $P_{\nu_\odot\to\nu_e} = P_{\nu_\odot\to\nu_\mu} = P_{\nu_\odot\to\nu_\tau} = \frac{1}{3}$