keV Dark Matter via the Supersymmetric Higgs Portal and Small Scale Structures

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References...

This talk is based on...

(1) John McDonald and Narendra Sahu, JCAP, 0806, 026 (2008)

(2) John McDonald and Narendra Sahu, arXiv:0809.0247[hep-ph]

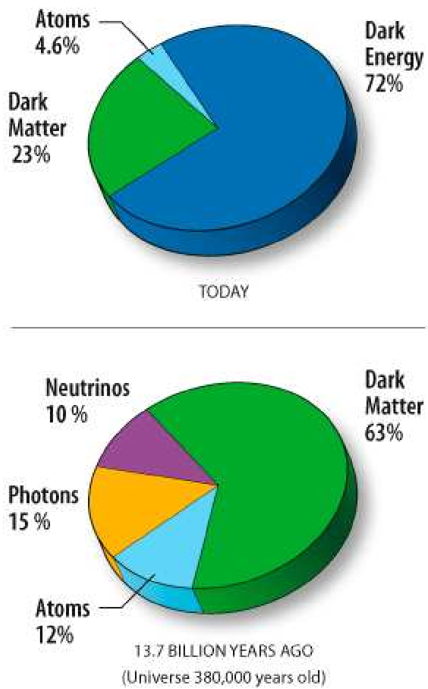
Introduction and Motivation...

It is presumed that the early universe went through a period of inflation and then reheated to a uniform temperature T_R, called ‘Reheating Temperature’.

Since then the Universe is cooled down to the present epoch at $T_0 = 2.75^\circ K$

During the course of reheating visible as well as dark matter (DM) could have been produced.

WMAP5 gives the total energy budget of the universe:



Neutrino and Radiation contribute less than a percent.

Nature of Dark Matter: Cold or Warm ?

Cold Dark Matter (CDM) with a cosmological constant (ΛCDM) is remarkably successful in explaining the large scale structure of the observed universe.

Numerical simulation based on ΛCDM model predicts:

- **cusped central density**
- **too many galactic sub-halos**
- **too low angular momentum of spiral galaxies**

The conflict between two can be resolved if dark matter is warm, preferably the mass is $\mathcal{O}(1)$ keV.

In this talk, I will present

- **the relic abundance of a keV warm dark matter (WDM)**
- **its structure formation properties**
- **its relation to reheating temperature T_R**

Stability of Dark Matter

While SM does not have any explanation for DM, one can extend it with an additional symmetry like Z_2 or $U(1)$ to incorporate a DM candidate.

In MSSM, R-parity is imposed, which is effectively a Z_2 symmetry.

The stability of the DM is then ensured by the surviving symmetry.

Z_2-Singlino WDM in Extended MSSM

Let us extend the MSSM by a chiral singlet with a portal type coupling:

$$W = W_{\mathrm{MSSM}} + \frac{f\chi^2 H_u H_d}{M_S} + \frac{M_{\overline{\chi 0}}\chi^2}{2}$$

where χ is odd under Z_2 and therefore is a candidate of DM and S is a messenger field through which the DM communicates to the visible world. The effective mass of singlino is then

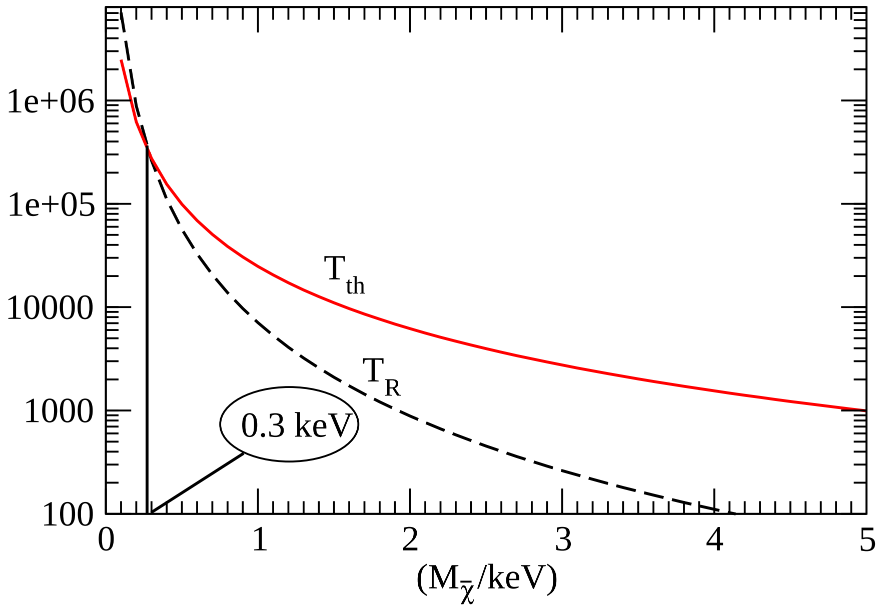
$$M_{\overline{\chi}} = M_{\overline{\chi}0} + M_{\overline{\chi}\ sb}$$

with $M_{\overline{\chi}\ sb} = fv^2 \sin 2\beta / M_S$, as $\tan\beta = \frac{\langle H_u \rangle}{\langle H_d \rangle}$

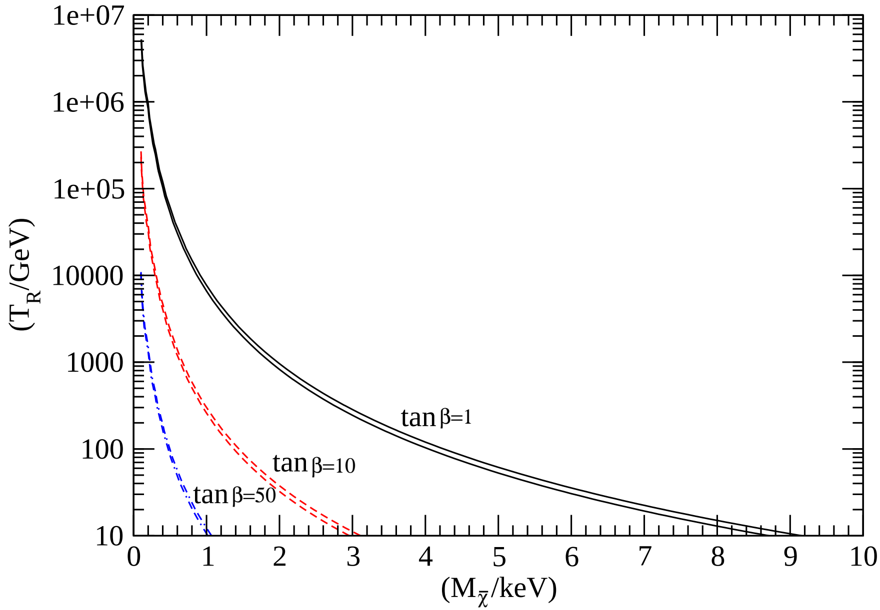
Relic Abundance of $\overline{\chi}$

Production of $\overline{\chi}$ occurs via the annihilation of thermal Higgs. The rate of $\overline{\chi}$ production per Higgs pair can be obtained by solving the Boltzmann equation:

$$\frac{dn_{\overline{\chi}}}{dt} + 3Hn_{\overline{\chi}} = \Gamma_{\overline{\chi}} n_H^{\mathrm{eq}}$$



The dependency of T_R and T_{th} on $M_{\overline{\chi}}$ is shown for $M_{\overline{\chi}} = M_{\overline{\chi}\ sb}$. T_{th} is obtained by setting $\Gamma_{\overline{\chi}} = H$.



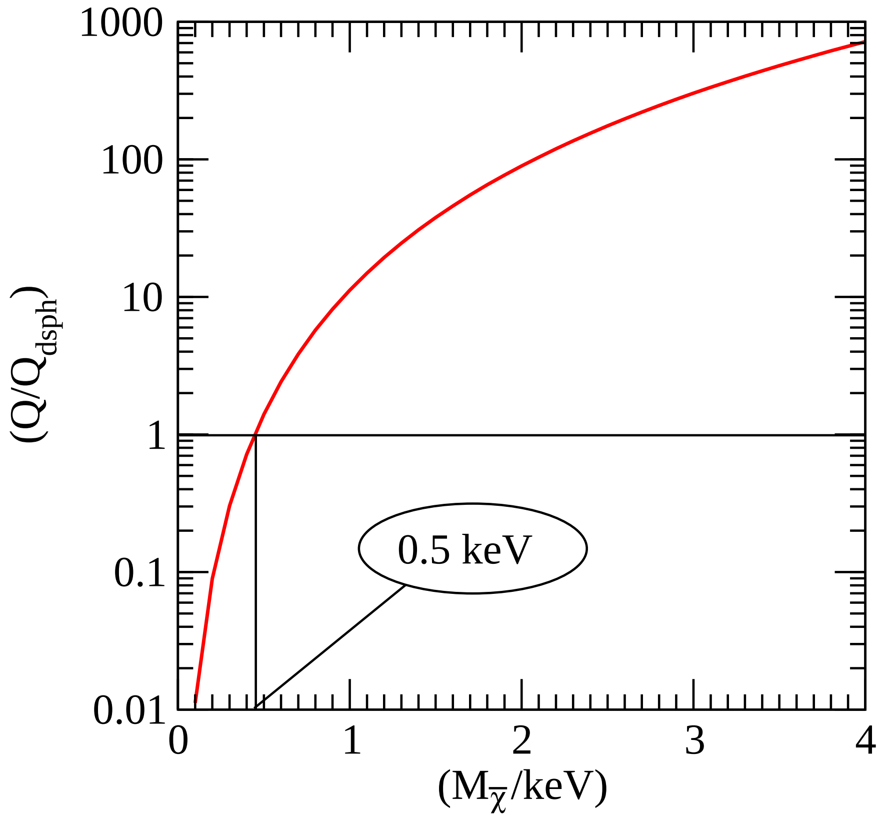
Contours of $\Omega_{\overline{\chi}} h^2 = 0.106 \pm 0.008$ **are shown in the plane of** $M_{\overline{\chi}}$ **versus** T_R **for different values of** $\tan\beta$. **The** $\overline{\chi}$ **mass is set to its value from symmetry breaking,** $M_{\overline{\chi}} = M_{\overline{\chi}\ sb}$. **Allowed Range:** [$0.3$ keV $\lesssim M_{\overline{\chi}} \lesssim 4$ keV]

Phase-Space Density

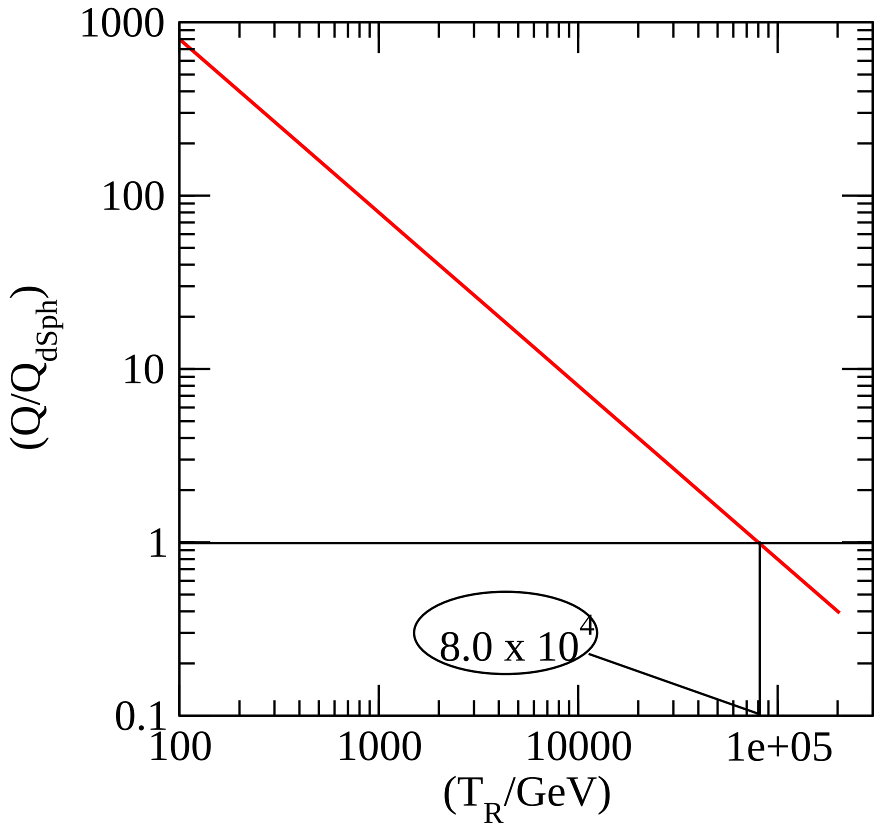
The phase-space density Q in terms of the distribution of $\overline{\chi}$ is given as:

$$Q \equiv \rho_{\overline{\chi}}/\sigma^3_{\overline{\chi}} = \frac{3^{3/2} M^3_{\overline{\chi}} \rho_{\overline{\chi}}}{\langle \vec{P}^2_{\overline{\chi}} \rangle^{3/2}}$$

Where $\sigma_{\overline{\chi}}$ is the one dimensional velocity dispersion and $\vec{P}_{\overline{\chi}}$ is the non-relativistic momentum of $\overline{\chi}$.



1000
100
10
1
0.1
0.01
0
1
2
3
4
(Q/Q_dsph)
(M_χ̄/keV)
0.5 keV



1000
100
10
1
0.1
(Q/Q_{dSph})
100
1000
10000
1e+05
(T_R/GeV)
8.0×10^4

Free-streaming Length of $\overline{\chi}$

The free-streaming length of any relativistic thermal relic can be given as:

$$\lambda_{\text{fs}} = \int_0^{t_{\text{NR}}} \frac{1}{R(t')} dt' + \int_{t_{\text{NR}}}^{t_{\text{eq}}} \frac{v(t')}{R(t')} dt'$$

$$= 0.073\ \text{Mpc} \left(\frac{1\ \text{keV}}{M_{\overline{\chi}}}\right) \left(\frac{10.75}{g(T_R)}\right)^{1/3} \left[\ln\left(\frac{t_{\text{eq}}}{t_{\text{NR}}}\right) + 2\right]$$

$$\approx 1.2\text{Mpc}$$

Sice $\overline{\chi}$ is decoupled from the thermal bath, λ_{fs} for $\overline{\chi}$ is given by

$$\lambda_{\overline{\chi}} \simeq 1.2\mathrm{Mpc}\left\langle\frac{p}{T}\right\rangle = (0.1 - 1)\mathrm{Mpc}$$

is perfect for suppressing sub-galactic halos.

Conclusions

(1) The Z_2-singlino ($\overline{\chi}$) of mass $\mathcal{O}(1)$ keV can be accounted for the observed phase-space density of dwarf spheroidal galaxies, thus explaining their non-singular cores.

If $\overline{\chi}$ mass comes entirely from the Higgs expectation value, then the observed abundance of dark matter implies that $M_{\overline{\chi}}$ is in the range 0.3-4 keV, which coincides exactly with the range required for $\overline{\chi}$ to act as WDM.

Conclusions Continued...

The model accounts for the phase-space density of dwarf spheroidal galaxies for $T_R \approx 10 - 100$ TeV.

The free-streaming length is $\mathcal{O}(0.1)$ Mpc, which may reduce the overproduction of satellites and loss of angular momentum observed in CDM simulations of galaxy formation.

Outlook

The small mass of $\overline{\chi}$ can be understood in terms of a large messenger mass, $M_S \approx 10^{10}$ GeV. Such a heavy S field might be identified with the messenger sector of gauge mediated SUSY breaking models.

The surviving Z_2 can be embedded in a $U(1)$ symmetry which, in any case, is required to solve the μ problem in MSSM.

Outlook Continued...

If R-parity is unbroken in the MSSM then the model can be extended to a mixed dark matter model (MDM), with the R-stabilized MSSM LSP providing CDM in addition to the Z_2-stabilized $\overline{\chi}$ WDM.

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THANK YOU