SuperWeakly Interacting Massive Particle Dark Matter

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Dark matter is one of the best evidence for new physics

WMAP DATA

$\Omega_{DM} = 0.23 \pm 0.04$

$\Omega_{Total} = 1.02 \pm 0.02$

$\Omega_{baryon} = 0.044 \pm 0.004$

More than 90 % is dark in our universe

What is the dark matter ? Why is the relic $\Omega_{DM} \sim O(0.1)$?

Stable, Non Baryonic
Large scale structure formation $\longrightarrow$ Not standard model particles

SUSY / Extra Dimension

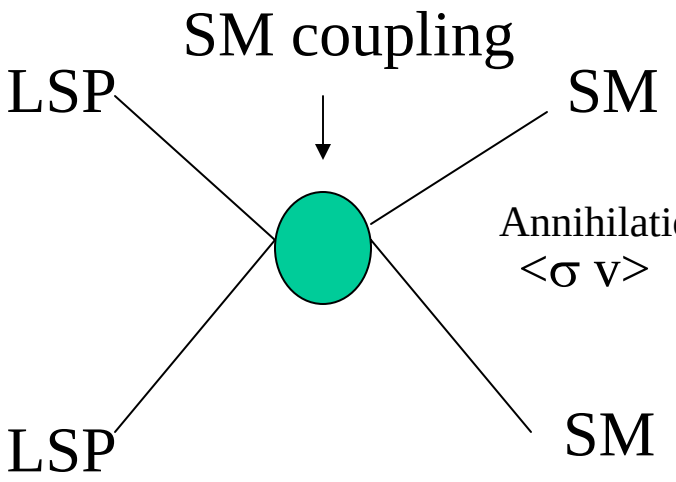
~ hierarchy problem

The extension introduces a partner/partners of SM particles and graviton with O(TeV) mass Super-partner / KK towers

The stability of the lightest partner is ensured by Z_2 parity.

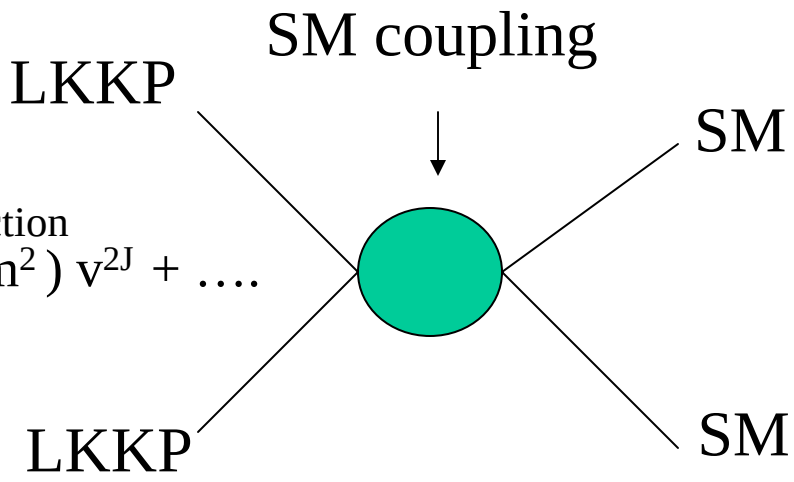
SUSY: R parity (forbid dim4 B, L violating terms)
ED : KK parity (a remnant of translational invariance for Extra Dims)

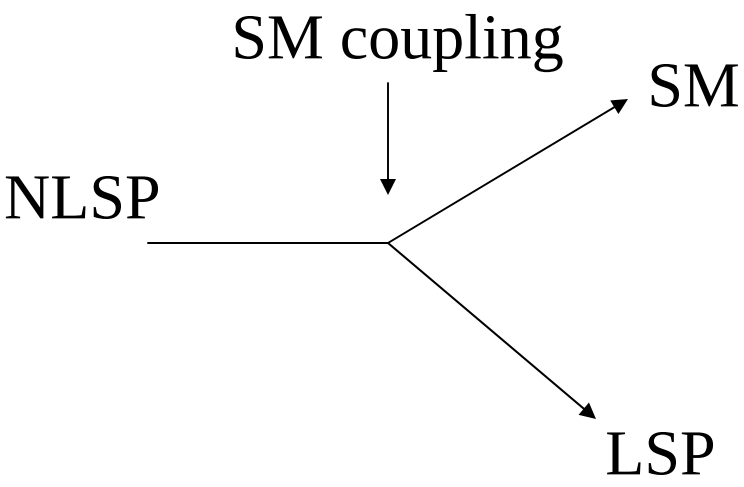
→ The lightest partner is a candidate of dark matter.

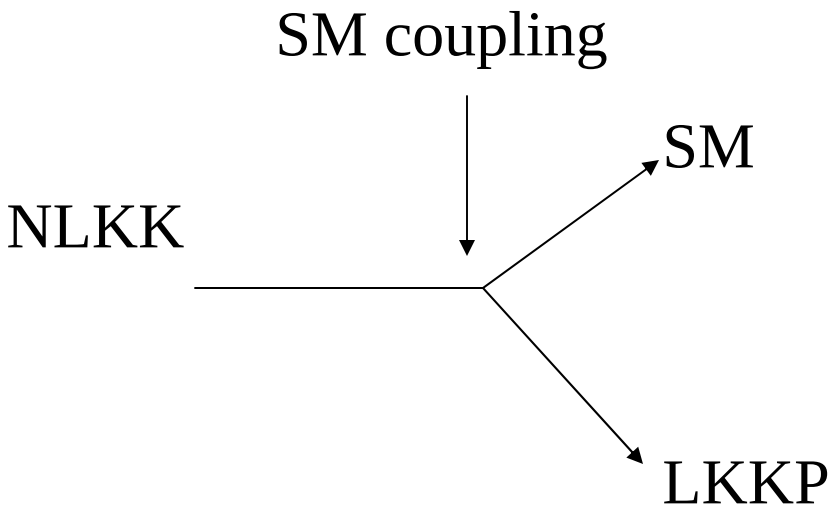


Annihilation cross section

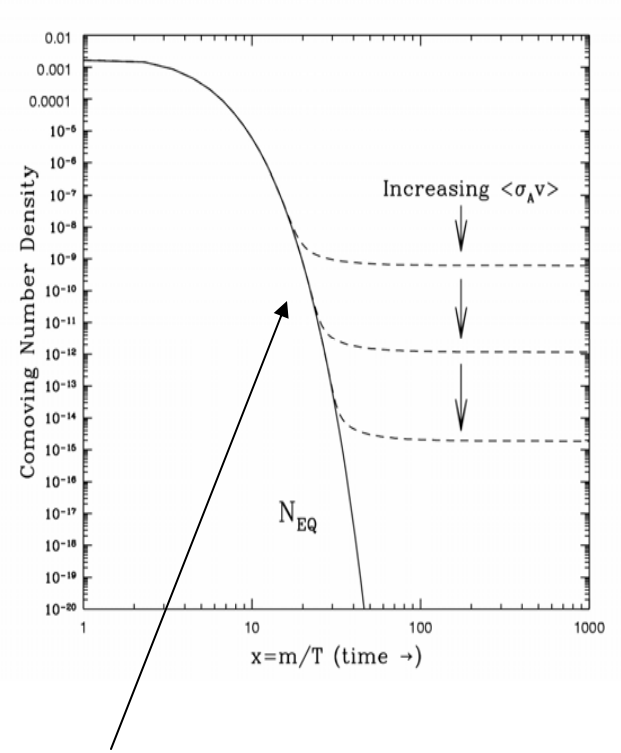
$\langle \sigma v \rangle \sim O(\alpha^2/m^2)\, v^{2J} + \ldots$







“ Thermal freeze out of Massive particle”



$\Omega \sim O(0.1)\,(x_F/20)\,(10^{-9}\,\mathrm{GeV}^{-2}/\langle\sigma v\rangle)$

$x_F = m/T \sim 6/v^2$

$\langle\sigma v\rangle \sim O(\alpha^2/m^2)\,v^{2J} + \ldots$

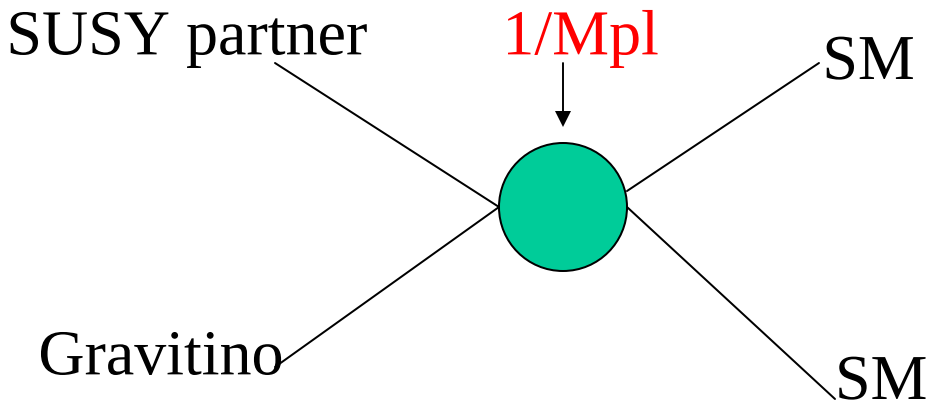
For EW interaction
(Neutralino, charged slepton, sneutrino)
m ~ O(0.1-1TeV) ←→ Ω ~ O(0.1)

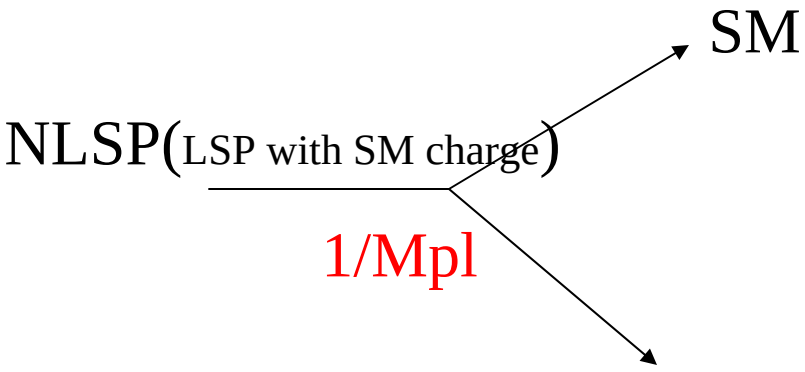
Expansion rate ~ $\langle\sigma v\rangle$ n
annihilation rate

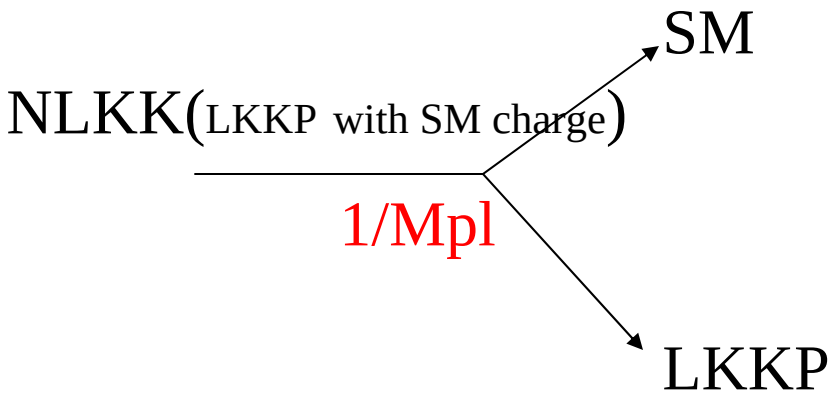
For colored interaction
(squark, gluino)
m ~ O(10-100TeV) ←→ Ω ~ O(0.1)

However, if the LSP/LKKP is the partner of graviton,

$(1/M_*)GS$ or $(1/M_*)GT$







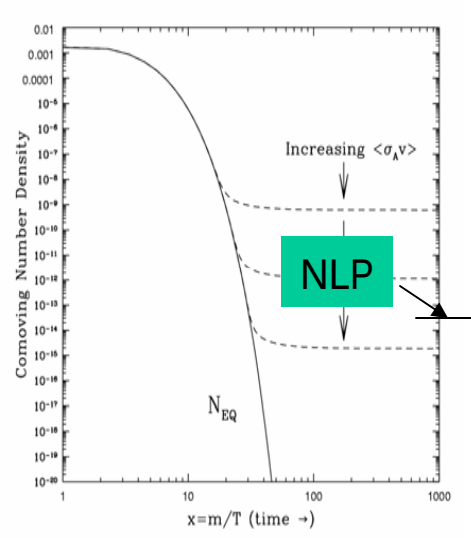
Not thermalized….

Gravitino, KK Graviton ?

We lose the natural explanation for dark matter relic density ??

SuperWeakly Interacting Massive Particles

J.Feng, A.Rajaraman, F.T (2003)



Thermally frozen NLPs obtain the desired relic density through the decoupling from thermal bath.

↓ After decoupling of NLPs

NLP → superWIMP+SM

$$\Omega_{superWIMP} \sim (m_{superWIMP}/m_{NLP})\Omega_{NLP} \sim \Omega_{NLP}$$

$$(m_{WIMP} \sim m_{superWIMP})$$

(This feature may be also shared by axino DM in SUSY model etc)

The relic is insensitive to the detail of the Early Universe before decoupling of NLPs from thermal bath.

NLSP= neutralino, charged slepton, sneutrino

SuperWeak coupling (~ Gravitational suppression)

Very small direct production cross section of superWIMP

→1. No hope for the direct production @ collider

No hope for the direct detection @ dark matter observations

→2. Suppression of the regeneration of the relic at reheating @early universe

NLPs have very long lifetime (~ O(year))

→1. NLP stable insider collider detector

→2. Late decay of NLPs = superWIMP production

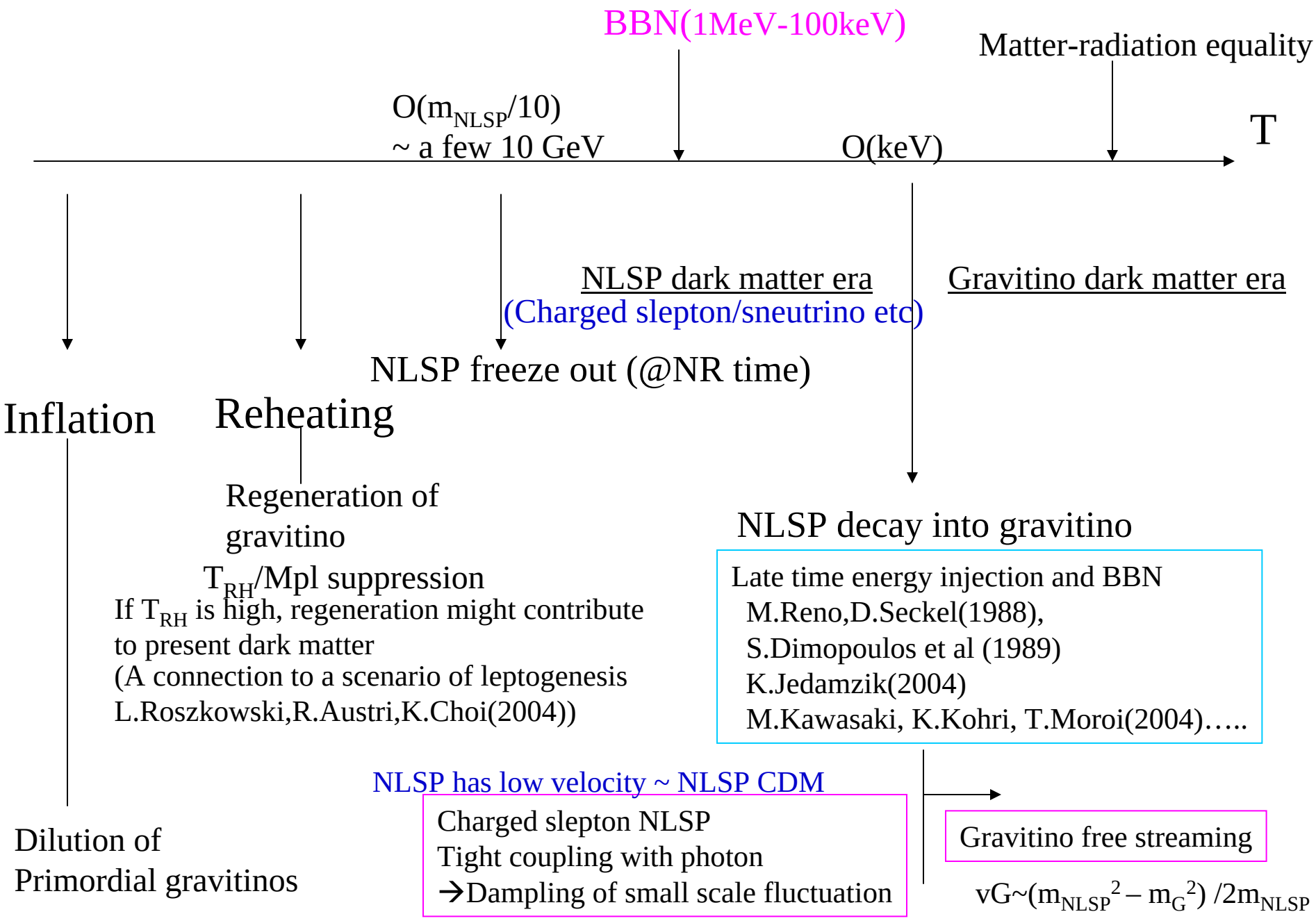
Recent/future development of cosmological/astrophysical observations

→Internal check of our knowledge

(BBN, CMB, Structure formation).

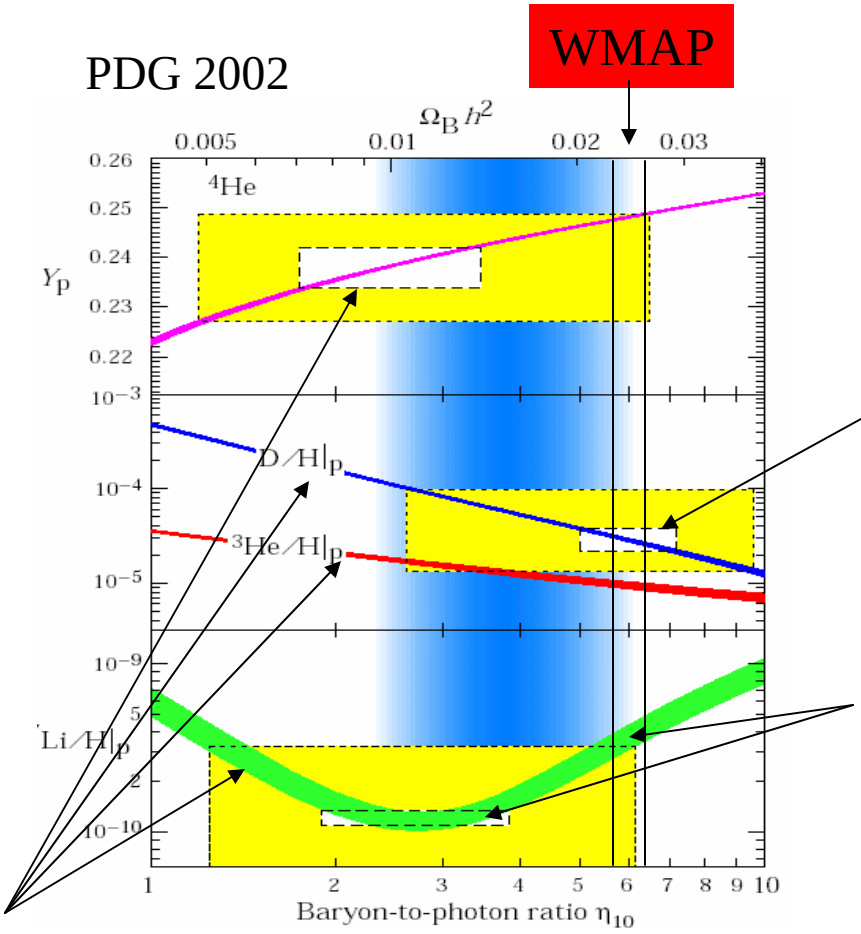
→possibilities to extract signals of new physics/to constrain them

←→ connection to collider physics


BBN(1MeV-100keV)
Matter-radiation equality
O(m_NLSP/10)
~ a few 10 GeV
O(keV)
T
NLSP dark matter era
(Charged slepton/sneutrino etc)
Gravitino dark matter era
NLSP freeze out (@NR time)
Inflation
Reheating
Regeneration of
gravitino
T_RH/Mpl suppression
If T_RH is high, regeneration might contribute
to present dark matter
(A connection to a scenario of leptogenesis
L.Roszkowski,R.Austri,K.Choi(2004))
NLSP decay into gravitino
Late time energy injection and BBN
M.Reno,D.Seckel(1988),
S.Dimopoulos et al (1989)
K.Jedamzik(2004)
M.Kawasaki, K.Kohri, T.Moroi(2004).....
NLSP has low velocity ~ NLSP CDM
Charged slepton NLSP
Tight coupling with photon
→Dampling of small scale fluctuation
Gravitino free streaming
vG~(m_NLSP^2 – m_G^2) /2m_NLSP
Dilution of
Primordial gravitinos

Present situation of BBN

Consistency needs “large systematic errors” in ^{7}Li.



Theoretical expectation lines (Standard BBN)

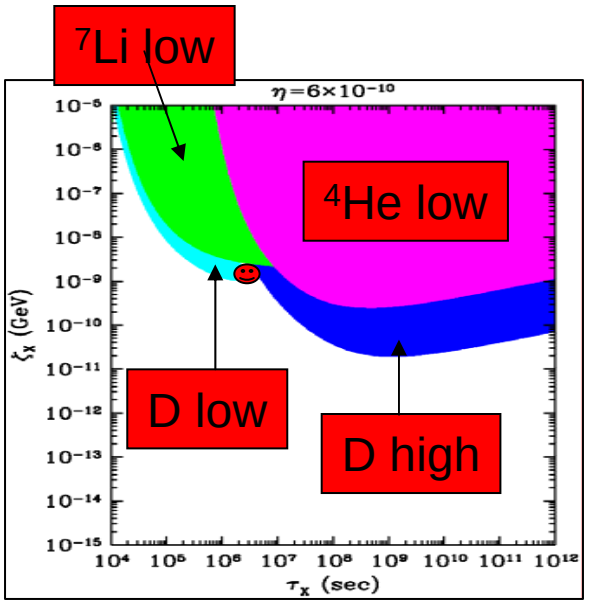
D/H:good agreement

$D/H_{obs}=D/H_{primordial}$?

The observed ^{7}Li seems not primordial.
…New physics may change them.

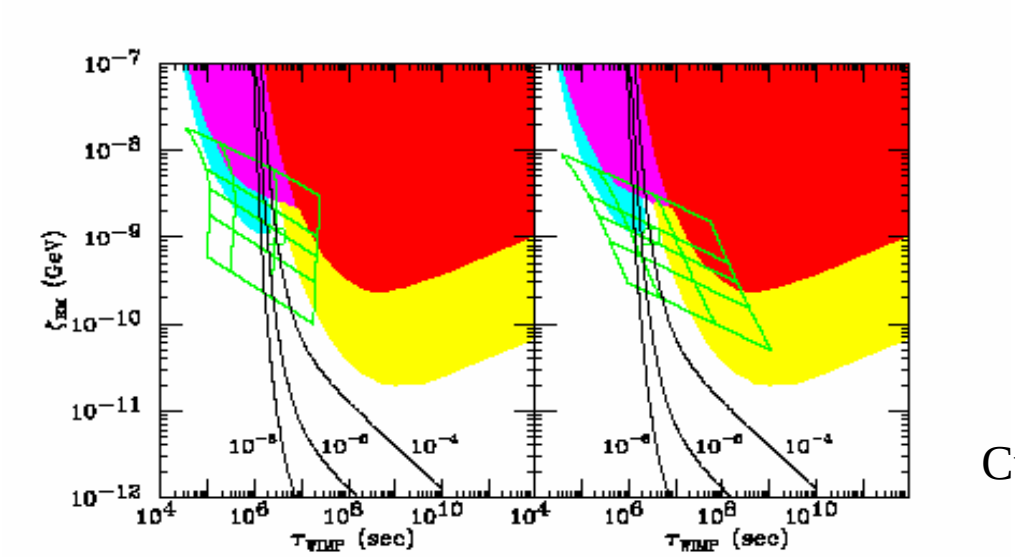
R.Cyburt,J.Ellis,D.Fields,K.Olive(2002)
J.Feng,A.Rajaraman,F.T(1003)
K.Jedamzik(2003)…..

The Diffuse Microwave Emission Survey(DMIES)
will be able to cover interesting region to explain low ^{7}Li.



R.Cyburt,J.Ellis,B.Field,K.Olive (2002)
(For EM energy injection)

Gravitino LSP



Neutralino→G+γ Stau→G+τ

Current limit
$\mu < 9\ 10^{-5}$
DIMES
$\mu < 2\ 10^{-6}$

J.Feng, A.Rajraraman, F.Takayama, Phys.Rev.D68 (2003) 063504

The ^{7}Li point may cause another problem (^{3}He/D)….. J.Ellis, K.Olive E.Bangioni (2005)

SuperWIMP dark matter and Structure formation of the Universe

J.Cembranos, J.Feng ,A.Rajaraman, F.T. hep-ph/0507150
M.Kalplinghat, astro-ph/0507300

NLSP decays into superWIMP = Non thermal (not adiabatic)
DM Phase space volume could be changed.

Before decay….NLSP dark matter = CDM phase space volume
After decay……Gravitino has larger velocity than NLSP

Relevant Free streaming may occur only after the decay of NLSP

What is the difference from thermal warm/cool dark matter ?

1.In principle, superWIMP scenario has Two parameters…..vG and τG
(Damping of power spectrum may not be controlled by only the information of phase space volume)

2.The momentum distribution of gravitino is not thermal but non-thremal form.
(The difference of momentum distribution might change the shape of dark matter small scale power. W.Lim,D.Huang,X.Zhang,R. Brandenberger(2001), M.Kamplighat(2005).)

3.Charged NLSP = Tight coupling with photon before the decay
(K.Sigurdson, M.Kamionkowski(2004))

Mediator is photon plazma

1.- The dark matter phase space volume can be decreased in the SWIMP scenario

Reducing the phase space density

$$Q \equiv \rho / \langle v^2 \rangle^{3/2}$$

J.Dalcanton, C.Hogan (2001)

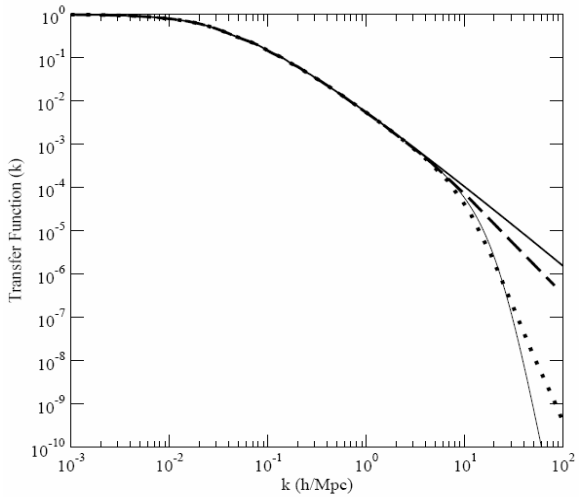
$$Q \simeq Q_0 \, u_X^{-3} \left[\frac{10^6 \text{ s}}{\tau_X} \right]^{\frac{3}{2}} \left[\frac{\Omega_{\text{SWIMP}} h^2}{0.11} \right]$$

$$Q_0 \equiv 1.0 \times 10^{-27} \text{ GeV}^4$$

2.- Small scales in the linear Power Spectrum are damped:

Free streaming only

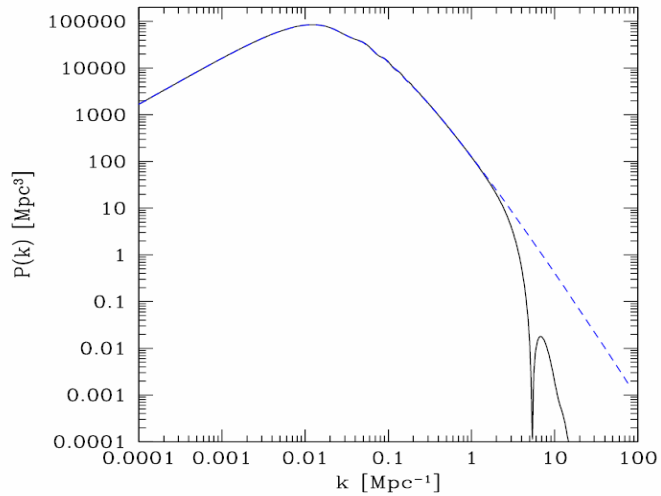
$$\lambda_{\text{FS}} \simeq 1.0 \text{ Mpc } u_X \left[\frac{\tau_X}{10^6 \text{ s}} \right]^{\frac{1}{2}}$$



M. Kaplinghat, astro-ph/0507300

Acoustic oscillation only

$$\lambda_{\text{A}} \simeq 7.2 \times 10^{-2} \text{ Mpc} \times \left[\frac{\tau_X}{10^6 \text{ s}} \right]^{\frac{1}{2}}$$

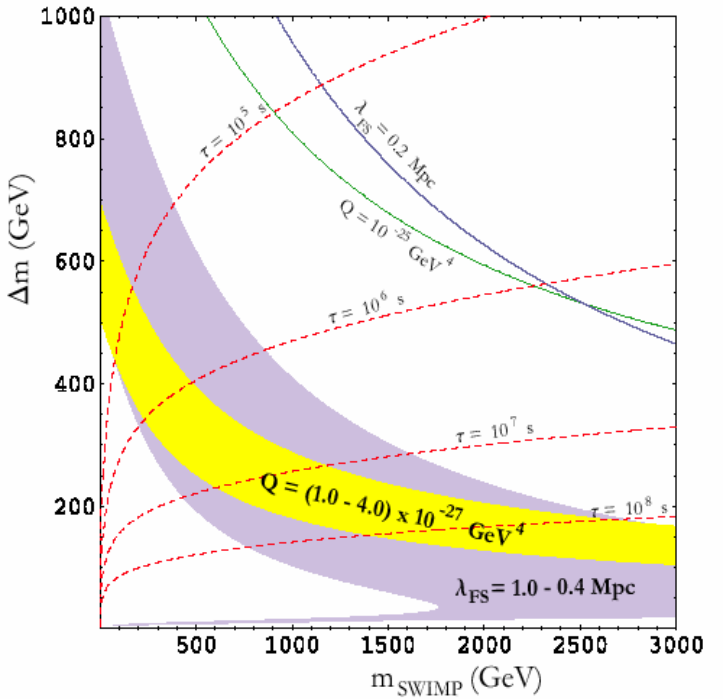


Sigurdson and Kamionkowski, PRL 92, 171302 (2004)

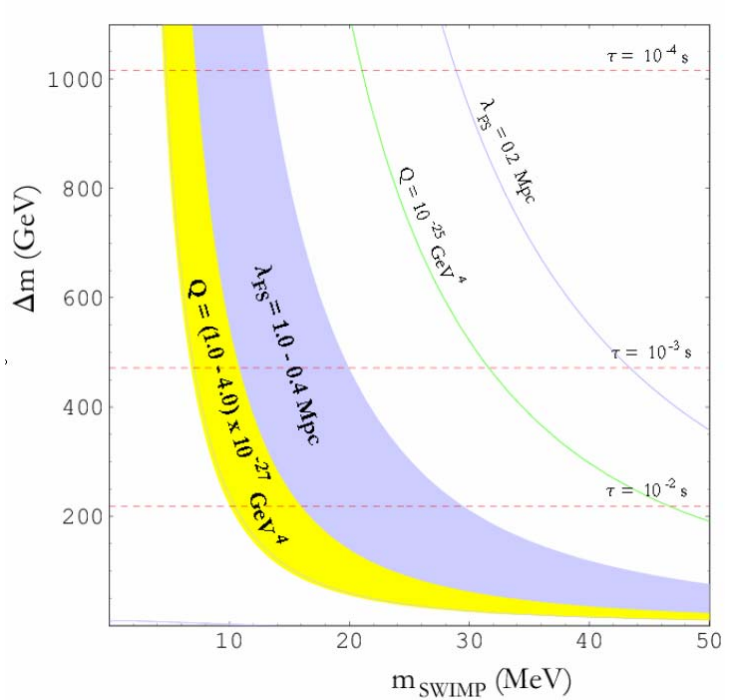
Free streaming only (in sneutrino NLSP case)

J.Cembranos,J.Feng,A.Rajaraman, F.T(2005)

$$\Delta m \equiv m_{\rm NLSP} - m_{\rm SWIMP}$$



Sneutrino→Gravitino+neutrino



Sneutrino→Axino+neutrino

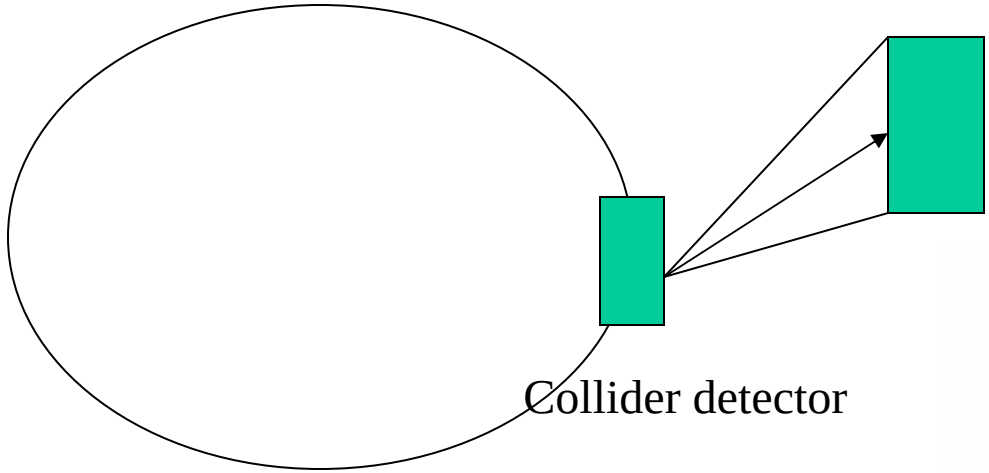
More details….Now under the study, J.Cembranos, M.Kaplinghat, Louie Strigari, F.T

Collider expermeints may be able to measure the detail feature of NLSP,
…….the charge, the spin, the mass, and the relic density

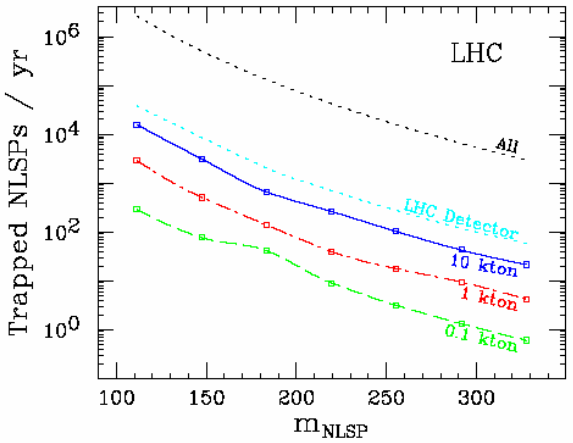
Charged NLSP trapping at Collider experiments and search for NLSP decays into Gravitino

J.L.Feng, B.Smith (2004)

K.Hamaguchi, Y.Kuno, T. Nakaya, M. Nojiri(2004)



Stau trapping tank

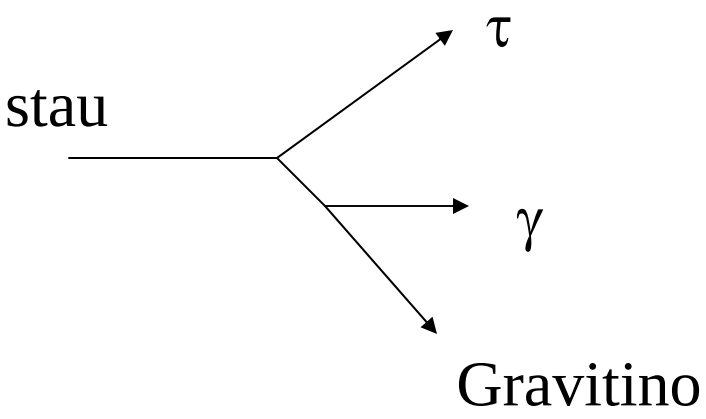


Measurement: the lifetime of NLSP and mass difference of NLSP and LSP gravitino,

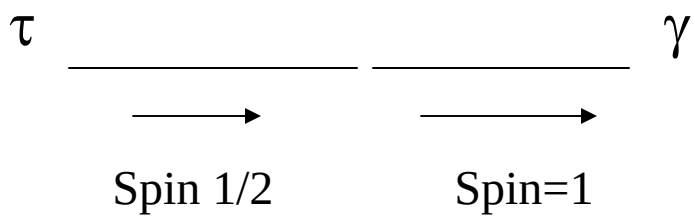
→ vG and τG

Spin measurement for gravitino and graviton

Buchmuler, Ratz, Hamaguchi, Yanagida(2004)



Angluar distribution may tell us spin 3/2



Summary

SuperWIMP is an attractive dark matter candidate.

SuperWIMP may provide rich indirect signals for cosmological/astrophysical observation and collider experiments

The further understanding of BBN, CMB and the role of dark matter features on structure formation may find the signals or constrain superWIMP scenario.