Gravitons and Dark Matter in Universal Extra Dimensions

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Universal Extra Dimensions

- Models beyond Standard Model (SM) frequently imply existence of extra dimensions (ED).
- Simplest incorporation of ED: Universal Extra Dimensions.
- All fields propagate in ED.
- Only one free parameter: m_{KK}~1/R.

Universal Extra Dimensions

- D = 5:

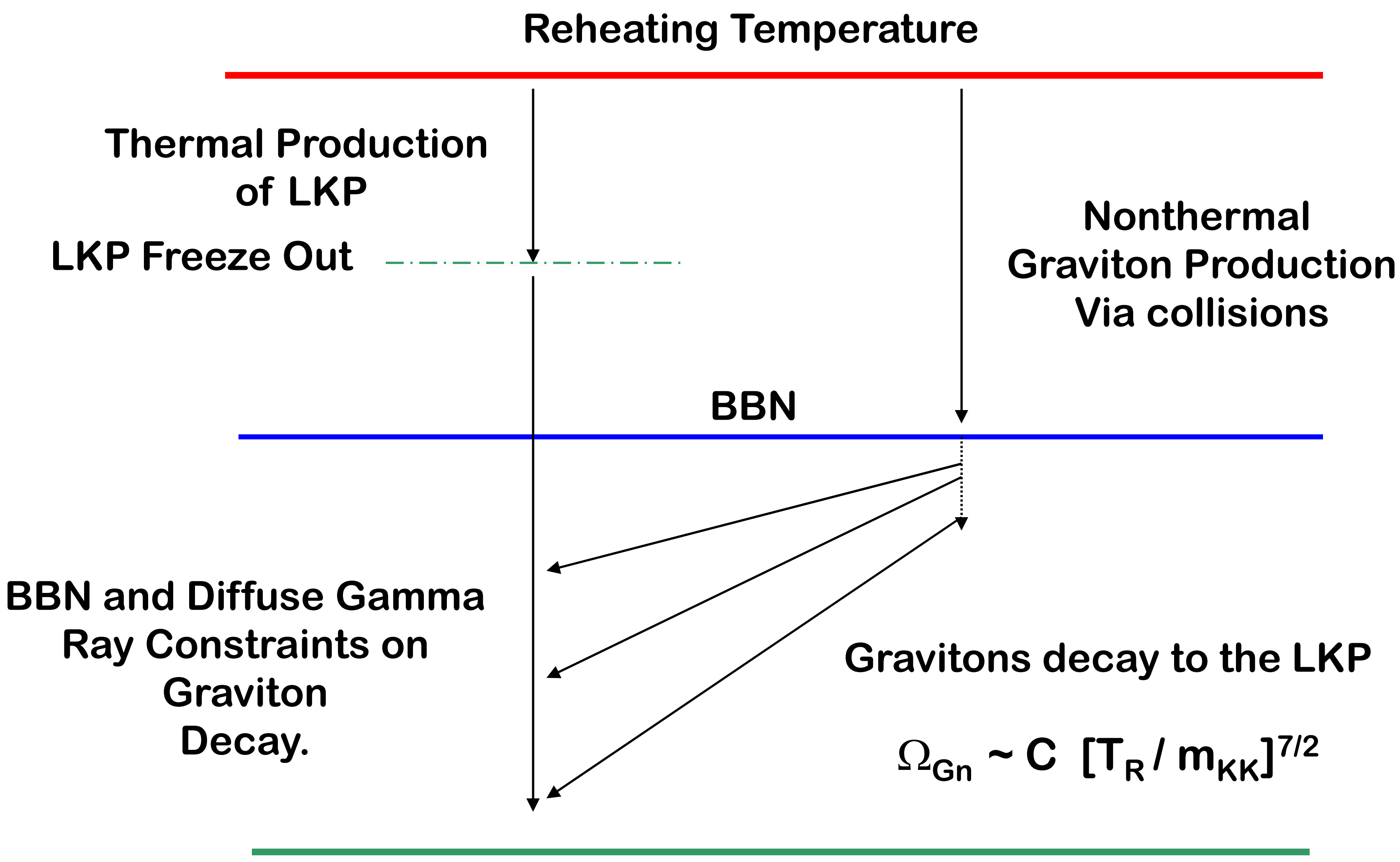
  $S^1/Z_2 \longrightarrow (-1)^{KK}$ KK Parity

  $\longrightarrow$ LKP Stable

  $\longrightarrow$ LKP DM Candidate w/ $m_{KK} \sim O(1)$ TeV

Gravitons?

- G^1 as the LKP very tightly constrained by Big Bang Nucleosynthesis (BBN) and diffuse gamma spectrum.
- Usually effect of the G^1 when it is not the LKP considered not important, since all interactions are Planck suppressed.
- We will show that in fact the gravitons can have significant effects on the DM density.



Reheating Temperature

Thermal Production of LKP

LKP Freeze Out

Nonthermal Graviton Production Via collisions

BBN

BBN and Diffuse Gamma Ray Constraints on Graviton Decay.

Gravitons decay to the LKP

$\Omega_{Gn} \sim C\ [T_R / m_{KK}]^{7/2}$

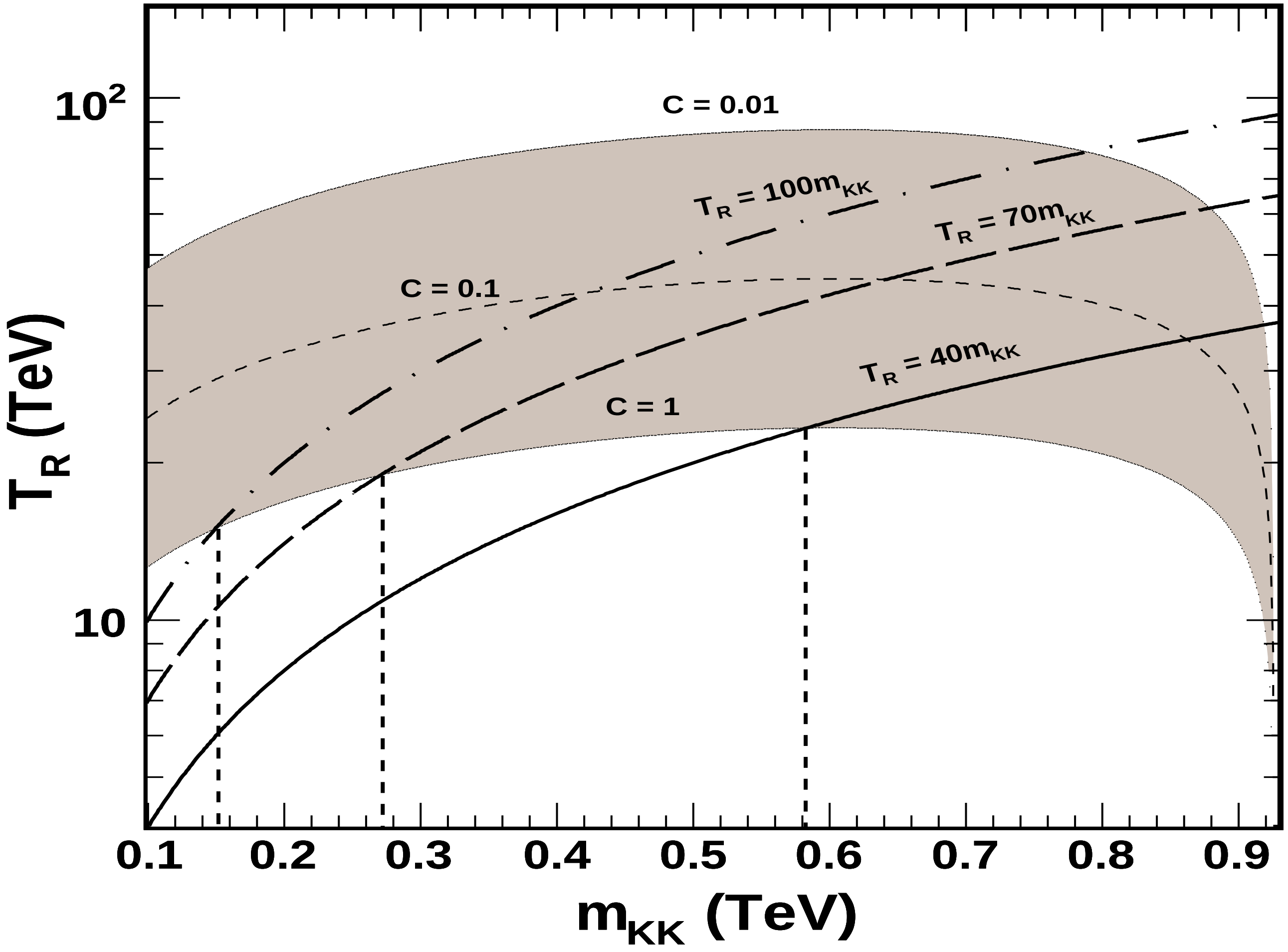
Present Day $\Omega_{DM} = \Omega_{LKP} + \Omega_{Gn}$

Reheating Temperature

- Demanding that $\Omega_{\mathrm{DM}} = \Omega_{\mathrm{LKP}} + \Omega_{\mathrm{Gn}}$ be consistent with observation, shows us that we can lower the LKP mass as much as we wish as long as the reheating temperature behaves accordingly:

$$T_R \simeq m_{\mathrm{KK}} \left[\frac{\Omega_{B^1}\rho_c - s_0 m_{\mathrm{KK}} d Y_\infty}{\alpha(d) C s_0 m_{\mathrm{KK}}^2} \right]^{\frac{2}{4+3d}}$$

Values of the reheating temperature obtained by demanding a proper DM density, for different values of the graviton production parameter C for D=5. Also shown are lines of constant ratios of the reheating temperature to the lightest KK mass.



Additional Contributions to the Annihilation Cross-Section

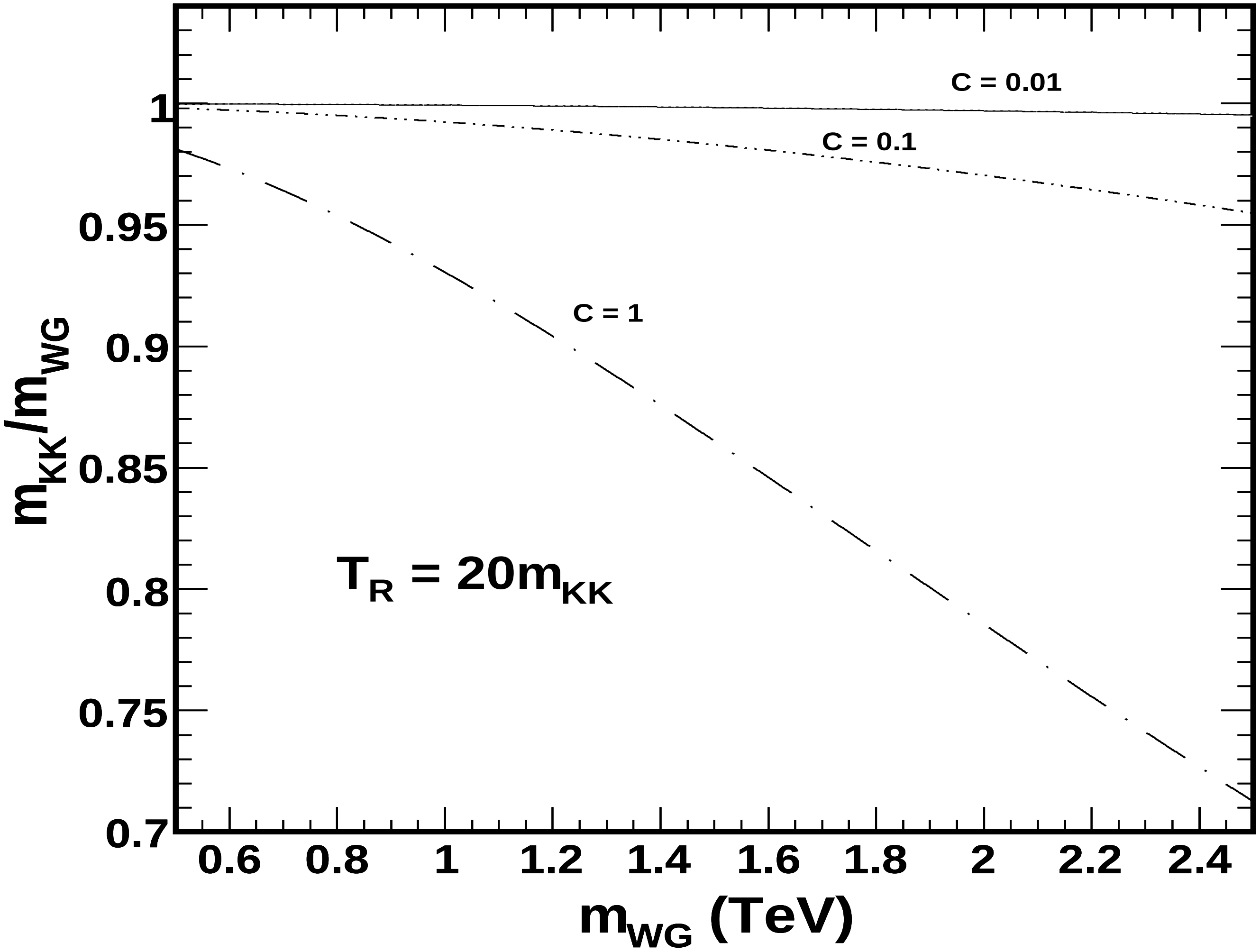
- A precise calculation for LKP density must include co-annihilation and second KK resonances effects. This changes the numerical results obtained, but the qualitative picture presented remains unchanged.
- These corrections can be quantified by noting that due to the weak logarithmic dependence of x_F, we can approximately parameterize Y as being proportional to m_{KK}:

$$Y_\infty = y\left(\frac{m_{\mathrm{KK}}}{\mathrm{TeV}}\right).$$

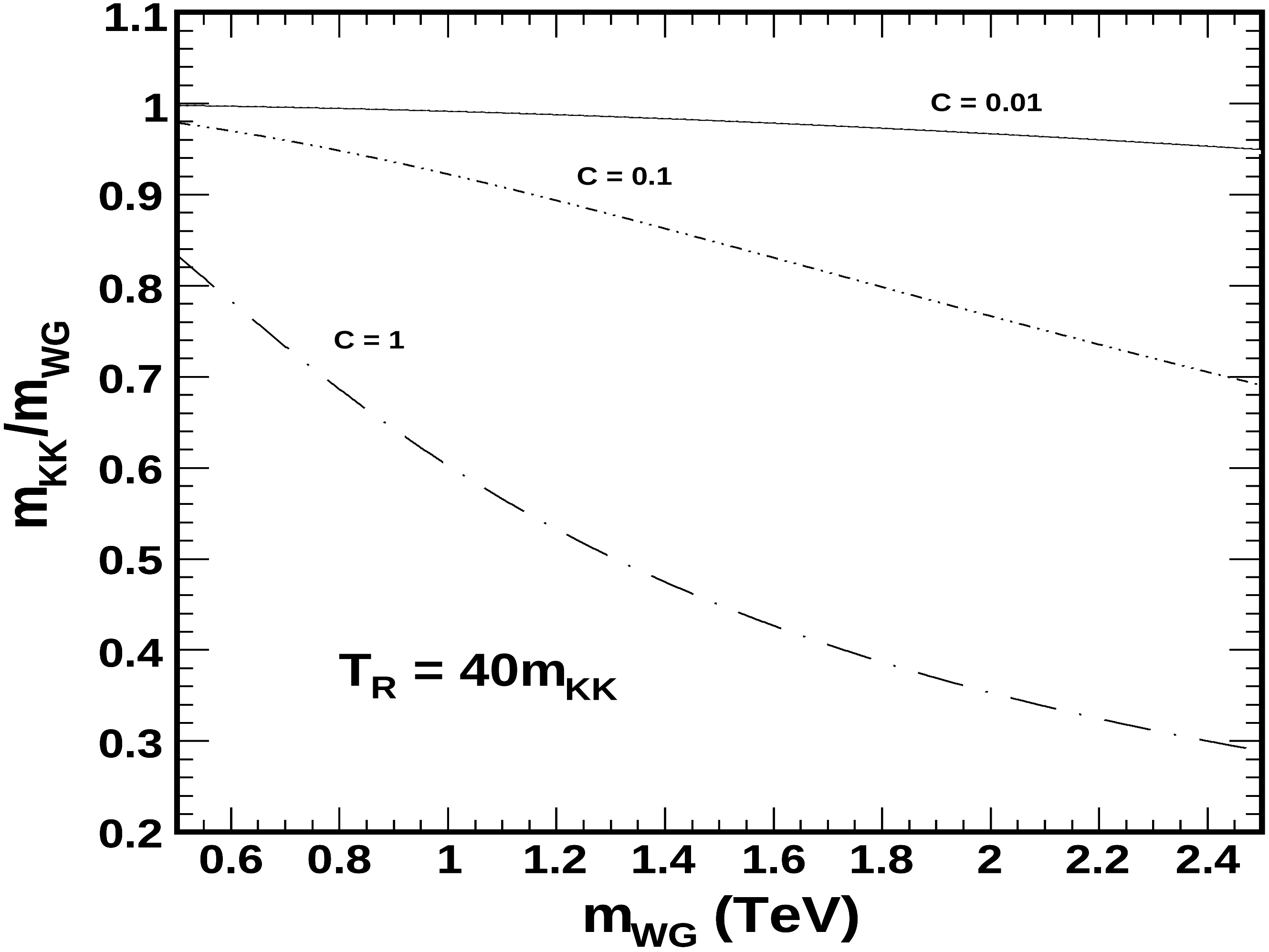
- The change in m_{WG} necessary to reproduce the correct DM density for a given T_R is given by:

$$\frac{m_{\mathrm{KK}}}{m_{\mathrm{WG}}} = \left(\frac{\Omega_{DM}\rho_c}{\Omega_{DM}\rho_c + \alpha(d) C s_0 m_{\mathrm{WG}}^2 \left[\frac{T_R}{m_{\mathrm{KK}}}\right]^{\frac{4+3d}{2}}}\right)^{1/2}$$

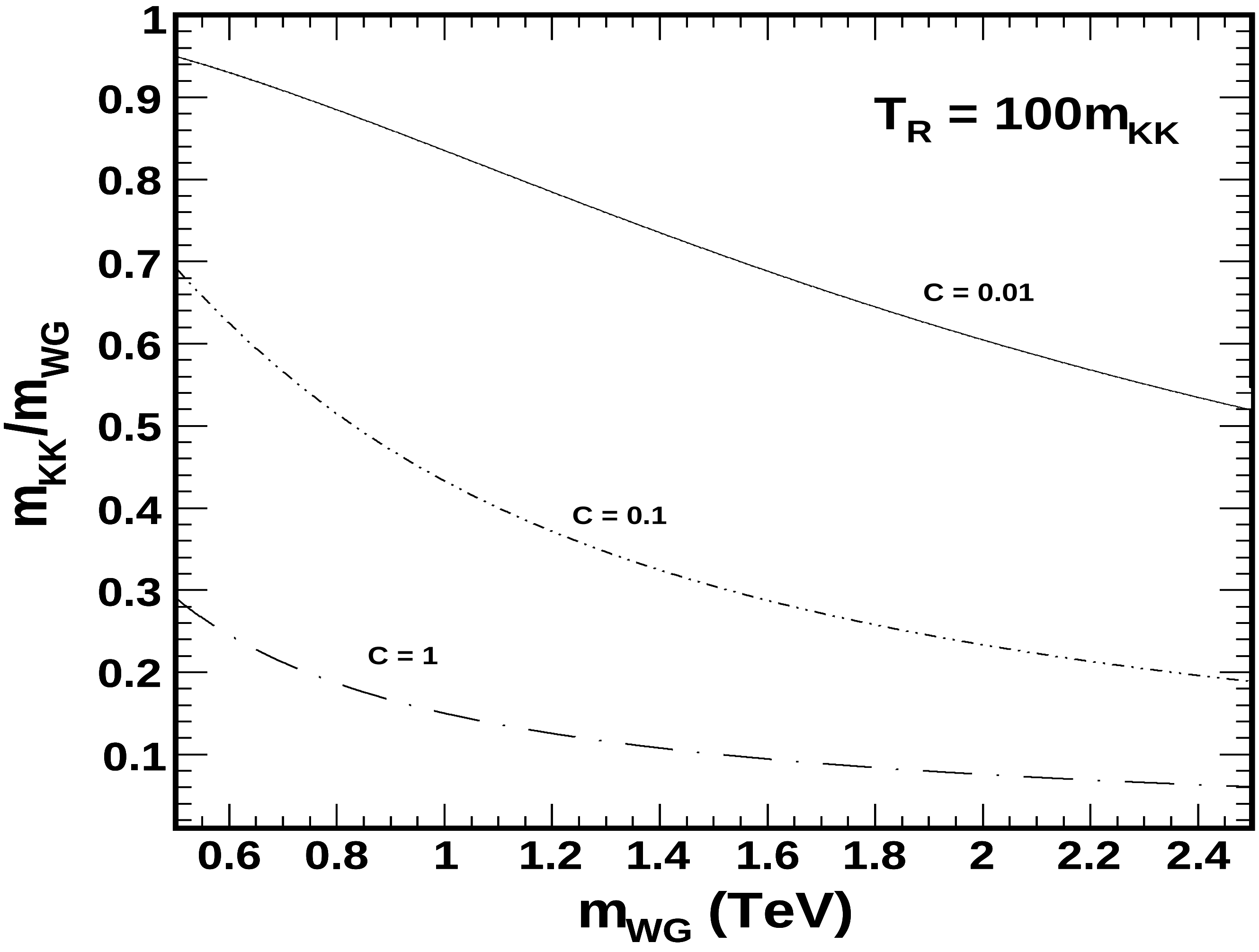
Values of the ratio of the LKP mass consistent with DM density to the one obtained in the absence of gravitons, m_{WG}, for $T_R = 20\ m_{KK}$ and D=5



$T_R = 40\ m_{KK}$, D = 5.


C = 0.01
C = 0.1
C = 1
$T_R = 40 m_{KK}$
m_{KK}/m_{WG}
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
m_{WG} (TeV)

T_R = 100 m_{KK}, D=5.


T_R = 100m_{KK}
C = 0.01
C = 0.1
C = 1
m_{KK}/m_{WG}
m_{WG} (TeV)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4

Decay Lifetimes

We found that G^n , for n>1, primarily decays to a pair of gauge bosons with equal KK numbers, with lifetime given by:

$$
\begin{aligned}
\tau(G^n) &= \frac{32\pi}{\sqrt{2}\cos^2\theta_W}\frac{M_4^2}{m_n^3}\sqrt{\frac{m_n}{\Delta_n}} \\
&\sim 1.76\times 10^5\ \mathrm{s}\left[\frac{\mathrm{TeV}}{m_n}\right]^{5/2}\left[\frac{\mathrm{TeV}}{\Delta_n}\right]^{1/2} \\
&\sim 5.56\times 10^6\ \mathrm{s}\frac{1}{n^3}\left[\frac{\mathrm{TeV}}{m_{\mathrm{KK}}}\right]^3
\end{aligned}
$$

$$\Delta_n \equiv m_{G^n} - 2m_{B^{\frac{n}{2}}} << m_{G^n}$$

$$\Delta_n \sim n\Delta_1 \equiv n(m_{G^1} - m_{B^1})$$

$$\Delta_1 \sim 10^{-3} m_{\mathrm{KK}}$$

Only long lived graviton is G^1, with a lifetime given by:

$$
\begin{aligned}
\tau(G^1) &= \frac{3\pi}{\cos^2\theta_W}\frac{M_4^2}{\Delta_1^3} \\
&\sim 2.33\times 10^4\ \mathrm{s}\left[\frac{\mathrm{TeV}}{\Delta_1}\right]^3, \\
&\sim 2.33\times 10^{13}\ \mathrm{s}\left[\frac{\mathrm{TeV}}{m_{\mathrm{KK}}}\right]^3
\end{aligned}
$$

Constraints on the G^1-B^1 mass difference.

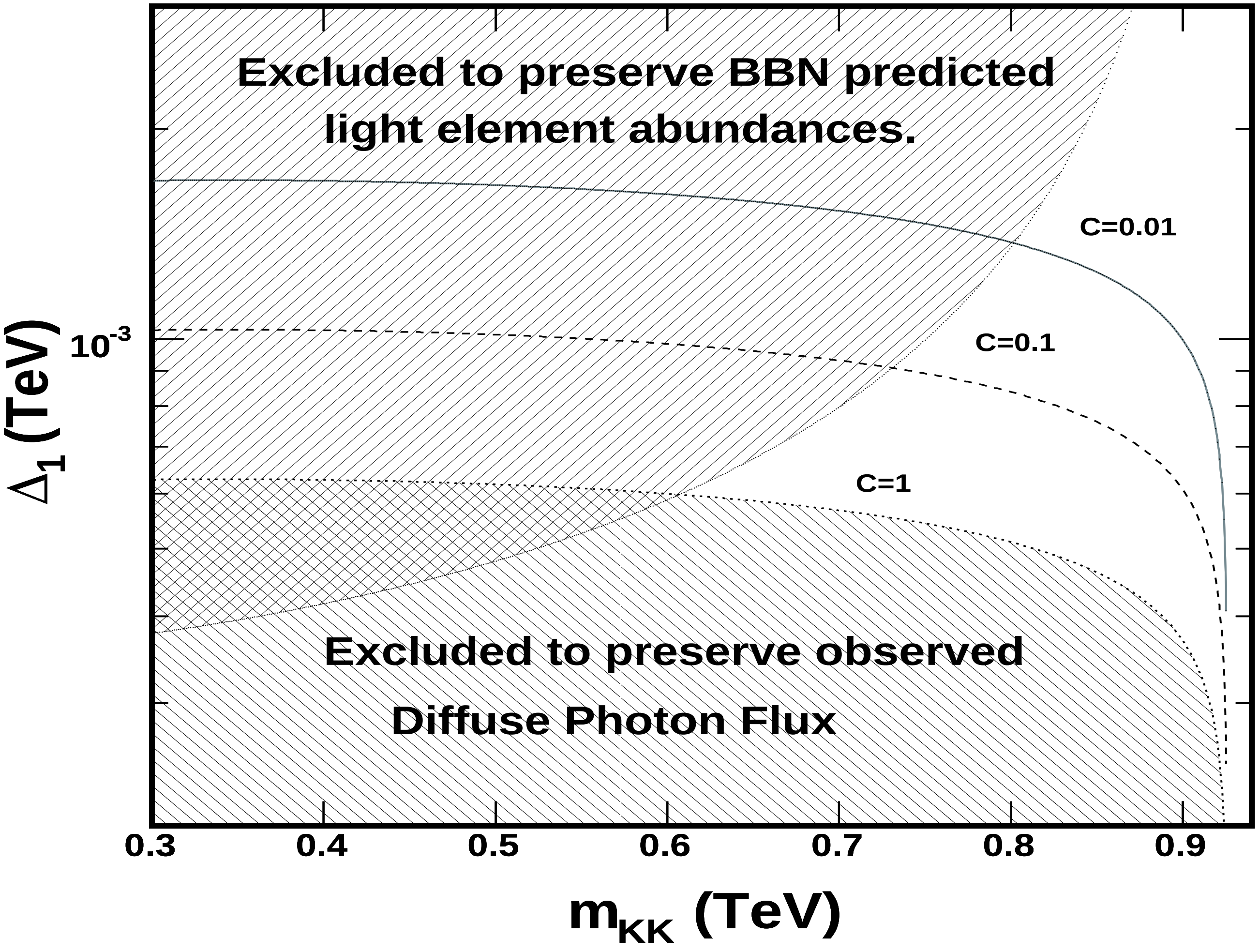
- If we assume that the reheating temperature is such that $\Omega = 0.23$, we find that to preserve BBN predicted light element abundances :

$$\delta m_{\rm KK} < \frac{n_\gamma \xi_B}{B_{\rm EM/Had}(\rho_c \Omega_{B^1} - m_{\rm KK} s_0 dY_\infty)}.$$

- Additionally requiring that late decays don’t destroy the diffuse photon flux:

$$\Delta_1 \; > \left(2.48 \times 10^{-3} \left(\left[\frac{T_R}{m_{\rm KK}}\right]^{3/2} - 1 \right) \left[\frac{m_{\rm KK}}{\rm TeV}\right] \right)^{1/2} \; {\rm GeV},$$

Combined constraints due to both BBN and observed diffuse flux on the mass difference.



One Loop Corrections to the KK Masses.

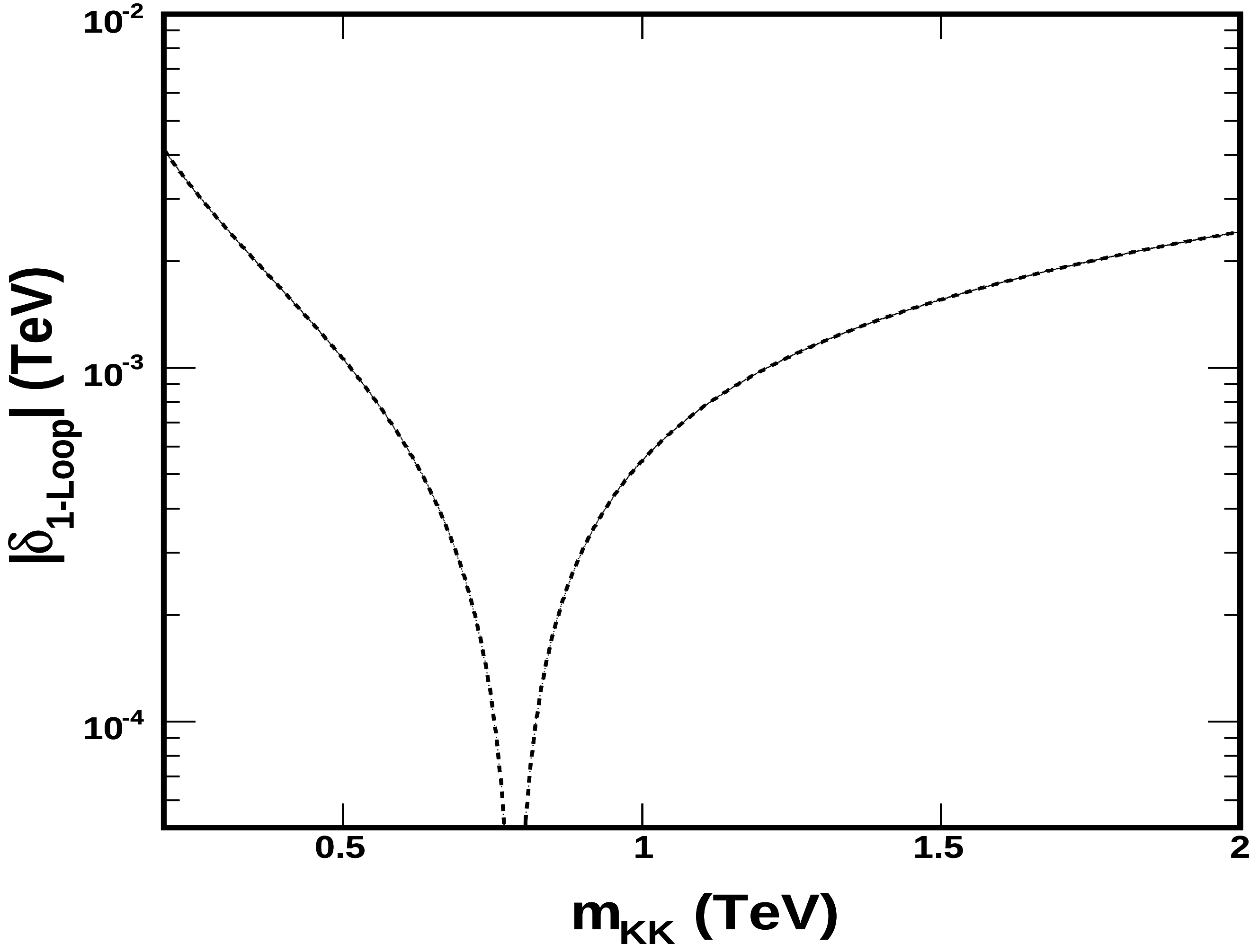
- The gauge boson mass matrix due to the Higgs vev in the B^n, W^{3n} basis:

$$\begin{pmatrix} \frac{n^2}{R^2} + \delta(m^2_{B^n}) + \frac{1}{4}\, g_1^2 v^2 & \frac{1}{4}\, g_1 g_2 v^2 \\ \frac{1}{4}\, g_1 g_2 v^2 & \frac{n^2}{R^2} + \delta(m^2_{W_3^n}) + \frac{1}{4}\, g_2^2 v^2 \end{pmatrix}$$

- Since the mixing is very small, the B^1 is very well approximated by:

$$\delta(m^2_{B^1}) \simeq -\left[\frac{39}{2}\,\frac{\alpha_1\zeta(3)}{4\pi^3} + \frac{1}{6}\,\frac{\alpha_1}{4\pi}\ln\frac{\Lambda^2}{\mu^2}\right]\left(\frac{1}{R}\right)^2 + \frac{g_1^2 v^2}{4}, \quad \mathrm{D{=}5}$$

Absolute value of the one loop corrections to the B^1 mass in the MUED as a function of m_{KK}. The graviton would be the LKP below masses ~ 800 GeV.

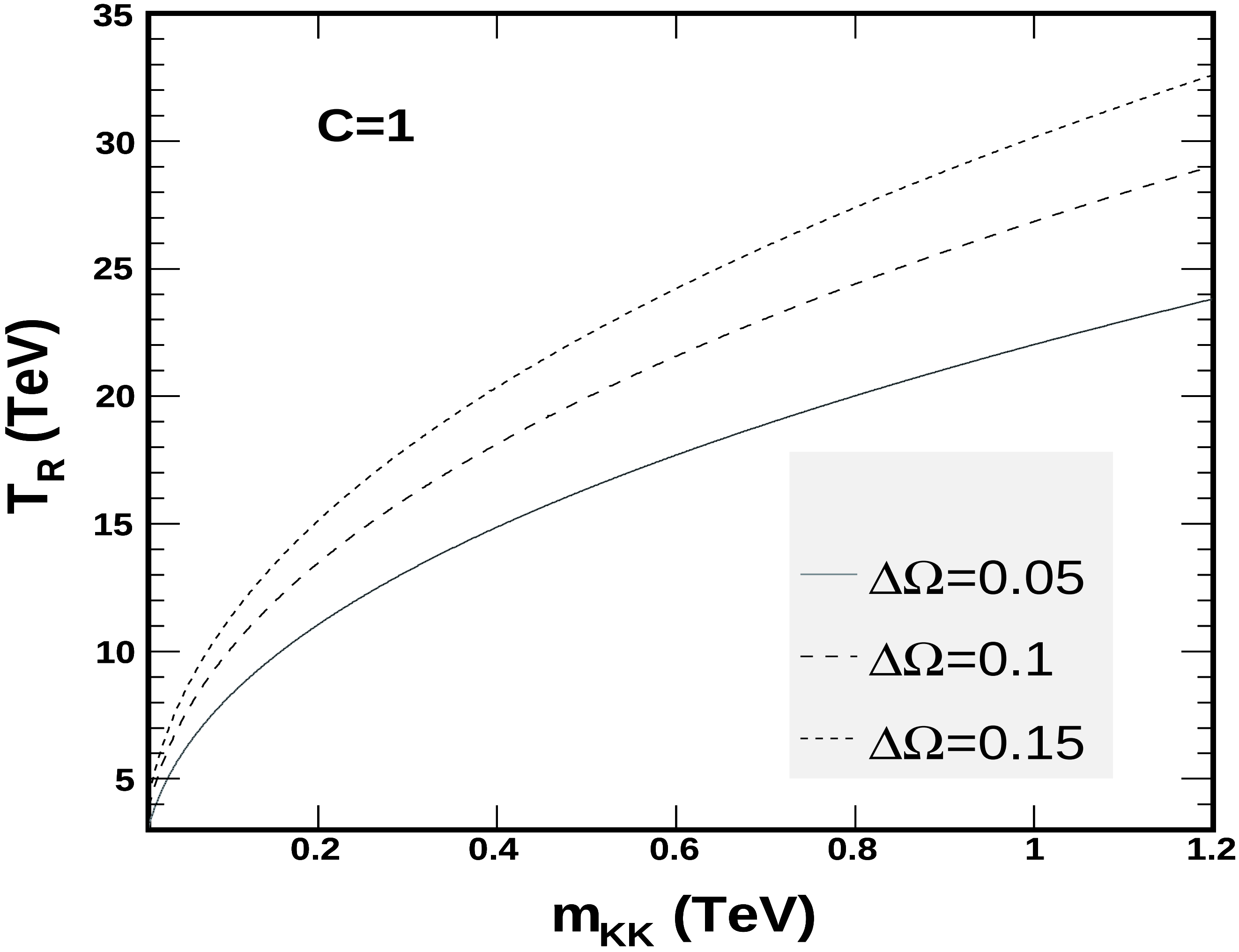


Determining the Reheating Temperature

- Due to small couplings to matter, provided the G^1 is not the LKP, it will not be produced in laboratory experiments.

- If conclusive evidence for UED is found in collider experiments, and relevant properties of the first and second modes were measured, then assuming that no other exotic particle exists, we could estimate the contribution of the G^n to the relic density, and therefore be able to infer the reheating temperature.

If LKP observed at LHC, the reheating temperature required to make up the deficit DM density by KK gravitons.



Conclusion

- We have studied the cosmological effects of the inclusion of the graviton tower in detail.
- Conventionally, due to Planck suppression, the graviton has been ignored. We have shown that it can in fact have significant effects.
- Requiring that the graviton decays don't destroy BBN predicted light element abundances and the diffuse gamma ray flux, we have obtained a bound on the mass difference between the G^1 and the LKP, which is consistent with the one obtained from one loop corrections in the MUED for a large range of values of m_{KK}.
- If UED is observed experimentally, we show that an upper limit on the reheating temperature can be deduced.