Discrete R-symmetry, Various Energy Scales and Gravitational Waves

Work in collaboration with W. Lin and T. Yanagida
Phys.Rev.D 105 (2022) 5, 055033 [arXiv:2201.03083]

Gongjun Choi (CERN)

Planck 2022, 30/May/2022

Outline

- Why discrete R-symmetry?
- Model
- Various energy scales
- Testing the model using Gravitational wave

Why discrete R-symmetry?

- Can be free of mixed anomalies within MSSM
  i.e. Z_{NR} x $[SU(2)_L]^2$, Z_{NR} x $[SU(3)_c]^3$

- R[Hu Hd] = 4 mod N → can avoid μ ~ M_P

- Can naturally suppress 1010105*
  (R[10 10 H_u]=2 mod N, R[10 5* H_d]=2 mod N,
  R[Hu Hd] = 4 mod N)

Why discrete R-symmetry?

- An interesting fact about R-symmetry
  → similar to “spacetime” symmetry
  → all operators in W should be charged

  → can dimensionful parameters below $\not{R}$ be commonly explained by the spurion of $\not{R}$?

Why discrete R-symmetry?

- An interesting fact about R-symmetry
  → similar to “spacetime” symmetry
  → all operators in W should be charged

  → can dimensionful parameters below $\not{R}$ be commonly explained by the spurion of $\not{R}$?

But, dangerous domain wall problem!

Inflation driven by R-symmetry breaking

- Simplest solution
  → dilute away domain walls by inflation

- Consider inflation driven by Z_{NR} breaking

- Infer a Z_{NR} breaking scale (v) from CMB observables

- Explain various energy scales with “v”

Model

- Symmetry group

$$G = Sp(2) \otimes Z_{6R} \otimes Z_6$$

- Particle content

	Q_i	S_{ij}	Φ	$\mathbf{5}^*$	$\mathbf{10}$	H_u	H_d	N	Z
$Sp(2)$	$\square$	-	-	-	-	-	-	-	-
Z_{6R}	1	0	3	0	0	2	2	0	4
Z_6	1	4	3	4	0	0	2	2	2

- Superpotential

$$W \supset -\lambda_{ij} S_{ij} Q_i Q_j + \lambda_{ij} g S_{ij} Q_i Q_j \Phi^2$$

$$+ \lambda_{H,ijk\ell} Q_i Q_j Q_k Q_\ell H_u H_d$$

$$+ \lambda_{N,ij} Q_i Q_j N N$$

$$+ \lambda_{Z,ijk\ell} Q_i Q_j Q_k Q_\ell Z \, .$$

Model

- Symmetry group

$$G = Sp(2) \otimes Z_{6R} \otimes Z_6$$

- Particle content

	Q_i	S_{ij}	Φ	$\mathbf{5}^*$	$\mathbf{10}$	H_u	H_d	N	Z
$Sp(2)$	$\square$	-	-	-	-	-	-	-	-
Z_{6R}	1	0	3	0	0	2	2	0	4
Z_6	1	4	3	4	0	0	2	2	2

- Superpotential

$$\begin{aligned} W \supset & -\lambda_{ij} S_{ij} Q_i Q_j + \lambda_{ij} g S_{ij} Q_i Q_j \Phi^2 \\ & + \lambda_{H,ijk\ell} Q_i Q_j Q_k Q_\ell H_u H_d \\ & + \lambda_{N,ij} Q_i Q_j N N \\ & + \lambda_{Z,ijk\ell} Q_i Q_j Q_k Q_\ell Z \, . \end{aligned}$$

$\not{R}$ - driven Inflation

Model

- Symmetry group

$$G = Sp(2) \otimes Z_{6R} \otimes Z_6$$

- Particle content

	Q_i	S_{ij}	Φ	$\mathbf{5}^*$	$\mathbf{10}$	H_u	H_d	N	Z
$Sp(2)$	$\square$	-	-	-	-	-	-	-	-
Z_{6R}	1	0	3	0	0	2	2	0	4
Z_6	1	4	3	4	0	0	2	2	2

- Superpotential

$$W \supset -\lambda_{ij} S_{ij} Q_i Q_j + \lambda_{ij} g S_{ij} Q_i Q_j \Phi^2$$
$$+ \lambda_{H,ijk\ell} Q_i Q_j Q_k Q_\ell H_u H_d$$
$$+ \lambda_{N,ij} Q_i Q_j N N$$
$$+ \lambda_{Z,ijk\ell} Q_i Q_j Q_k Q_\ell Z \, .$$

Higgsino mass

Model

- Symmetry group

$$G = Sp(2) \otimes Z_{6R} \otimes Z_6$$

- Particle content

	Q_i	S_{ij}	Φ	$\mathbf{5}^*$	$\mathbf{10}$	H_u	H_d	N	Z
$Sp(2)$	$\square$	-	-	-	-	-	-	-	-
Z_{6R}	1	0	3	0	0	2	2	0	4
Z_6	1	4	3	4	0	0	2	2	2

- Superpotential

$$W \supset -\lambda_{ij} S_{ij} Q_i Q_j + \lambda_{ij} g S_{ij} Q_i Q_j \Phi^2$$

$$+ \lambda_{H,ijk\ell} Q_i Q_j Q_k Q_\ell H_u H_d$$

$$+ \lambda_{N,ij} Q_i Q_j N N$$

$$+ \lambda_{Z,ijk\ell} Q_i Q_j Q_k Q_\ell Z \, .$$

RH neutrino mass

Model

- Symmetry group

$$G = Sp(2) \otimes Z_{6R} \otimes Z_6$$

- Particle content

	Q_i	S_{ij}	Φ	$\mathbf{5}^*$	$\mathbf{10}$	H_u	H_d	N	Z
$Sp(2)$	$\square$	-	-	-	-	-	-	-	-
Z_{6R}	1	0	3	0	0	2	2	0	4
Z_6	1	4	3	4	0	0	2	2	2

- Superpotential

$$W \supset -\lambda_{ij} S_{ij} Q_i Q_j + \lambda_{ij} g S_{ij} Q_i Q_j \Phi^2$$

$$+ \lambda_{H,ijk\ell} Q_i Q_j Q_k Q_\ell H_u H_d$$

$$+ \lambda_{N,ij} Q_i Q_j N N$$

$$+ \lambda_{Z,ijk\ell} Q_i Q_j Q_k Q_\ell Z \,.$$

SUSY-breaking

Model

- In confined phase of Sp(2), deformed moduli constraint

$$\rightarrow \qquad \langle Q_i Q_{i+1} \rangle = v^2 = \frac{\Lambda_*^2}{(4\pi)^2} \quad \text{for} \quad i = 1, 3, 5$$

- Quark bilinear condensation gives

$$W_{\text{eff}} \supset -\lambda \Lambda_*^2 S (1 + g\Phi^2)$$
$$+ \lambda_H \Lambda_*^4 H_u H_d + \lambda_N \Lambda_*^2 N N + \lambda_Z \Lambda_*^4 Z$$

Model (inflation)

- With the Kahler potential,

$$K(\Phi, S) \supset |S|^2 + |\Phi|^2 + c|S|^2|\Phi|^2 + \ldots$$

the first term leads to

$$V(\phi) \simeq \Lambda_*^4 e^{\frac{\phi^2}{2}} \left(1 - g\frac{\phi^2}{2}\right)^2 \left(1 + c\frac{\phi^2}{2}\right)^{-1}$$

A_s ~ 2.1 x 10-9
n_s ~ 0.96
R < 0.036

at k_{pivot} ~ 0.05Mpc^{-1}

→

Φ_{pivot}~0.6
Λ_*~10^{-3}
c>~0.4
g~0.3

Model (various energy scales)

- Next three terms

$$W_{\rm eff} \supset -\lambda\Lambda_*^2 S(1+g\Phi^2)$$

$$+\lambda_H \Lambda_*^4 H_u H_d + \lambda_N \Lambda_*^2 NN + \lambda_Z \Lambda_*^4 Z$$

Higgsino, RH neutrino mass and $\cancel{SUSY}$

Relevant physics	Energy scale
R-symmetry breaking	v $(\sim 10^{15}\mathrm{GeV})$
SUSY breaking	v^2 $(\sim 10^{12}\mathrm{GeV})$
Inflation scale $(H_{\rm inf})$	v^2 $(\sim 10^{12}\mathrm{GeV})$
Higgsino mass (μ_H)	v^4 $(\sim 10^5 - 10^6\mathrm{GeV})$
Right-handed neutrino mass (m_N)	v^2 $(\sim 10^{11} - 10^{12}\mathrm{GeV})$

→ $m_{3/2}$~100-1000TeV

Model (various energy scales)

- Reheating can be achieved via

$$\mathcal{O}_{\Phi N} = c_{\Phi N} |\Phi|^2 |N|^2$$

- Given m_Φ, $m_N \sim 10^{12}$GeV,

$$\Gamma(\phi \to 2N) \simeq (m_N/M_P)^2 (m_\Phi/8\pi) \simeq 1\text{GeV}$$

→ $T_{RH} \sim 10^9$GeV

Testing the Model via GW

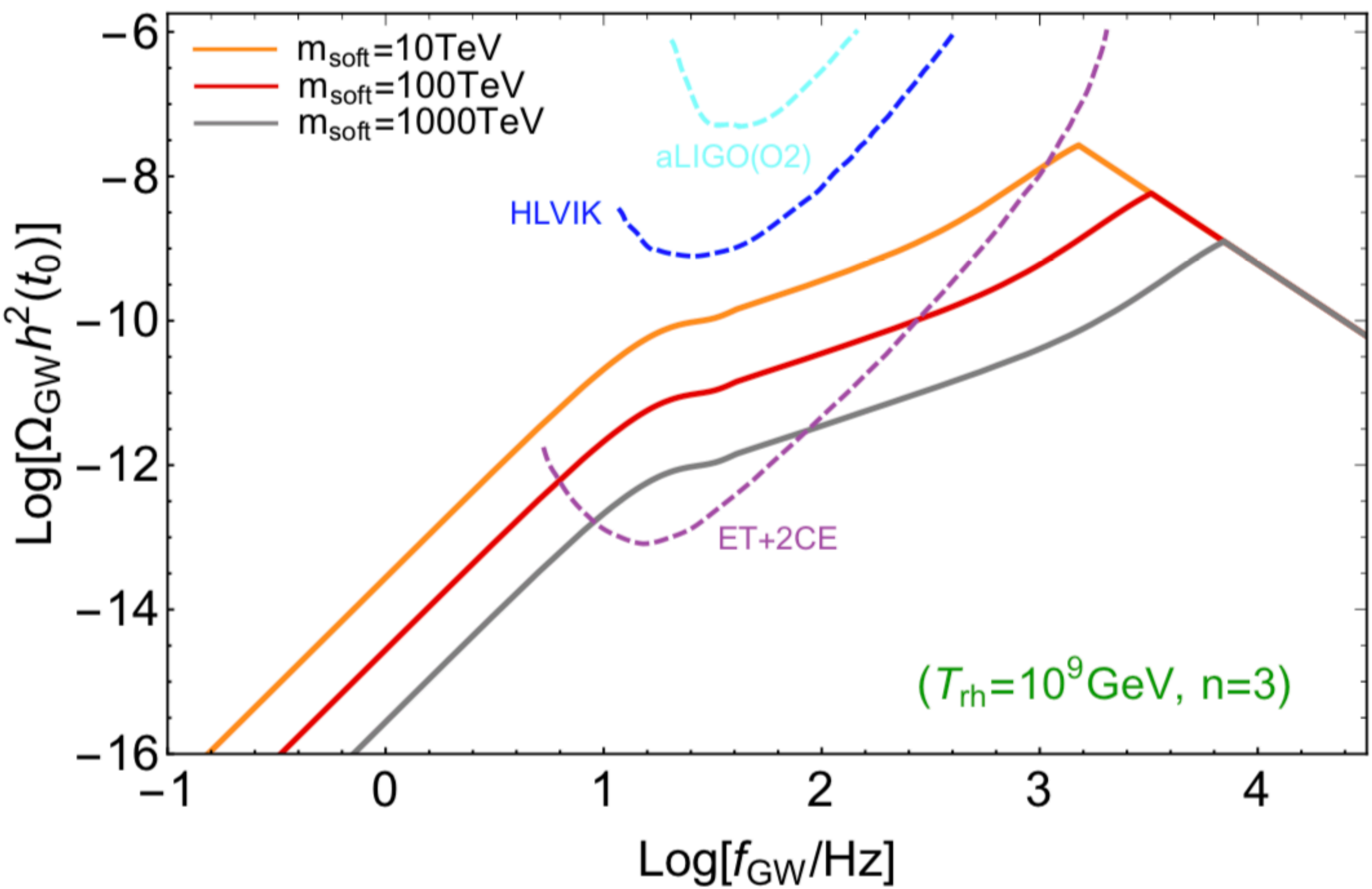
- $T_{RH} \sim 10^9$GeV and $m_{soft} \sim m_{3/2} \sim$ 100-1000TeV

- Consider a flat direction χ carrying B-charge

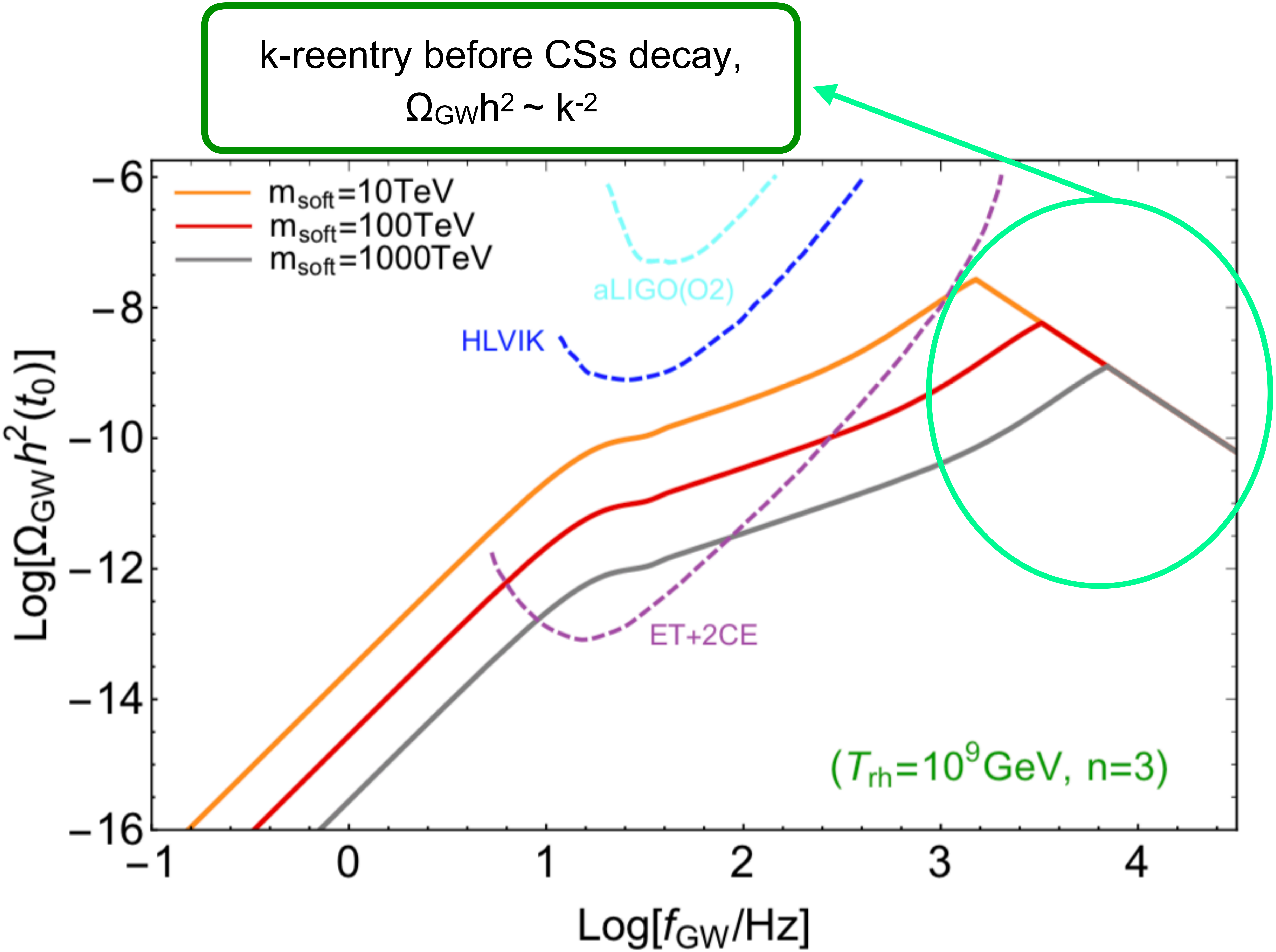
- If χ couples to S and Φ in Kahler potential with positive and negative coefficients (+ for S, - for Φ)
  → $\langle\chi\rangle = 0$ during inflation, but $\langle\chi\rangle \sim M_P$ during reheating

- Cosmic strings form due to $U(1)_B$-breaking during reheating → can produce GW

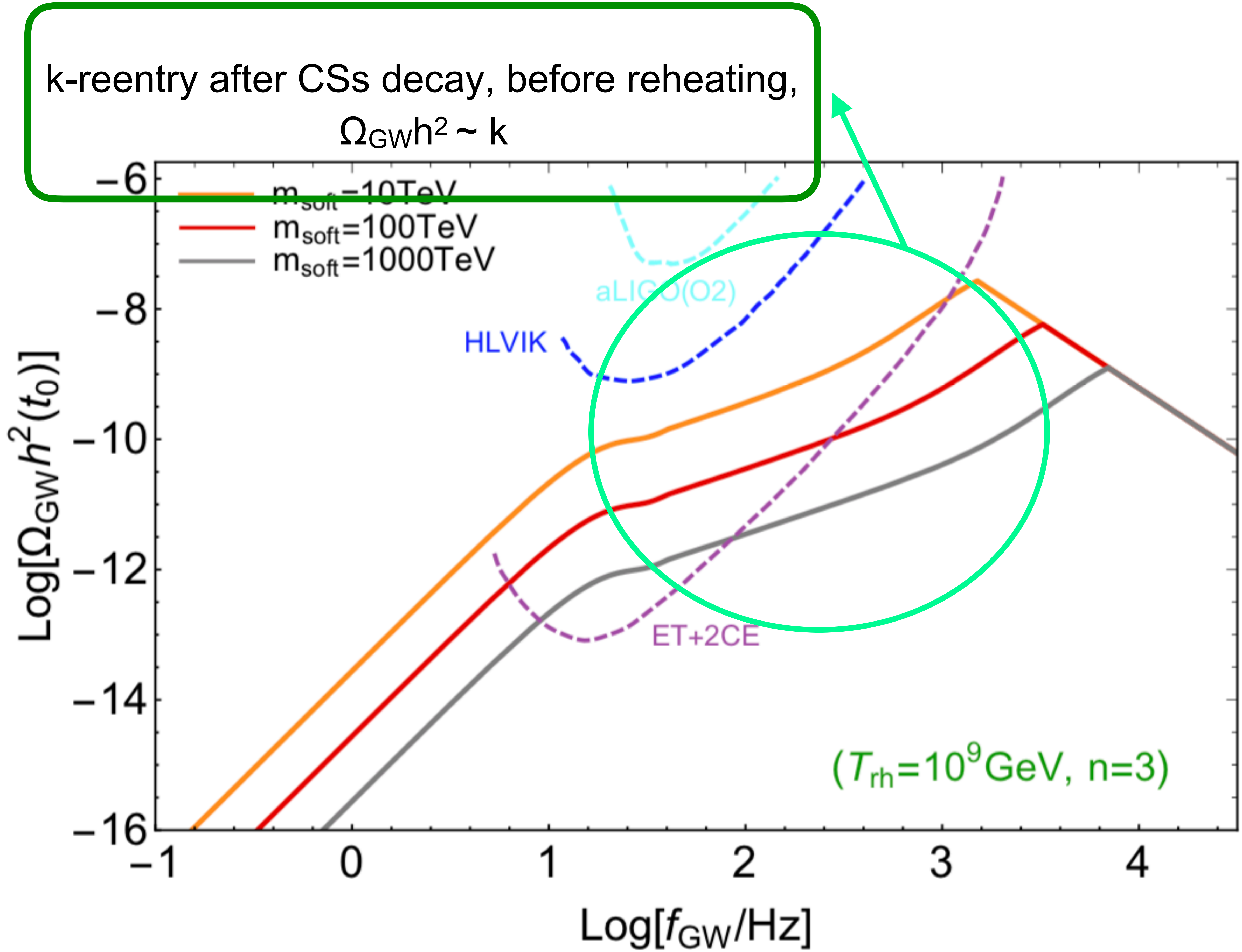
A. Kamada and M. Yamada [arXiv:1505.01167]



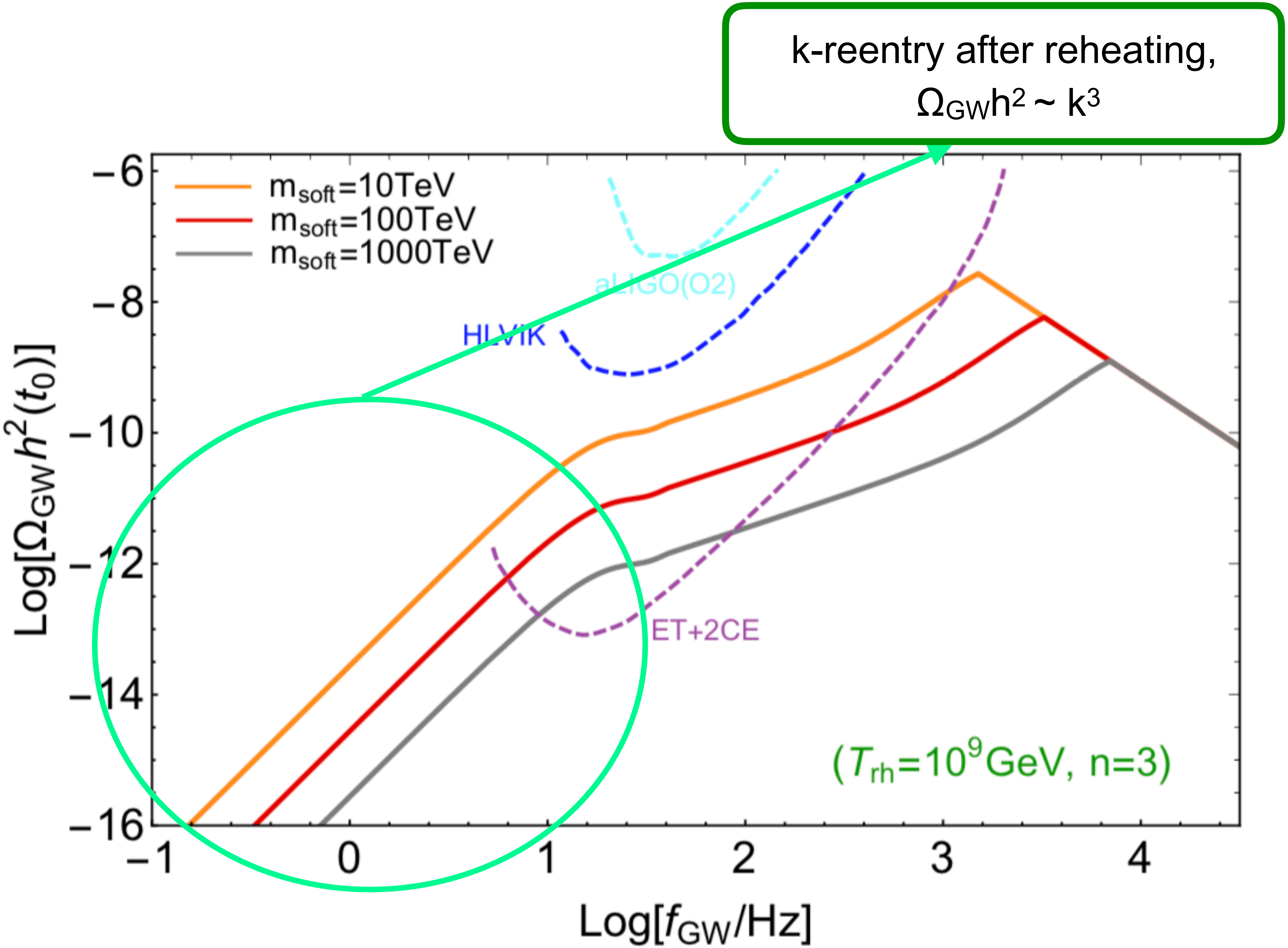
m_soft=10TeV
m_soft=100TeV
m_soft=1000TeV
aLIGO(O2)
HLVIK
ET+2CE
(T_rh=10^9GeV, n=3)
Log[Ω_GW h^2(t_0)]
Log[f_GW/Hz]
−6
−8
−10
−12
−14
−16
−1
0
1
2
3
4



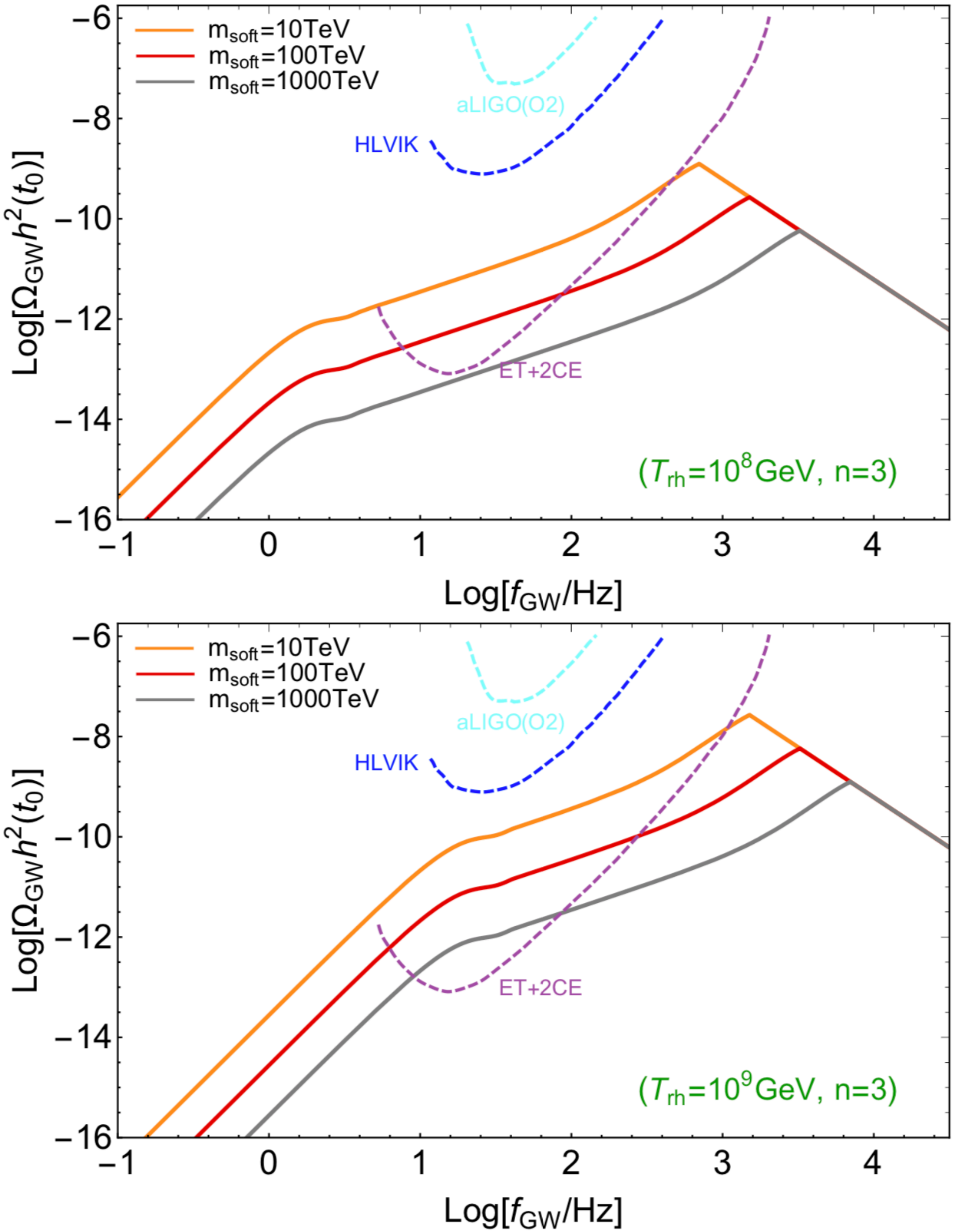
k-reentry before CSs decay,
ΩGWh2 ~ k-2
msoft=10TeV
msoft=100TeV
msoft=1000TeV
aLIGO(O2)
HLVIK
ET+2CE
(Trh=10^9GeV, n=3)
Log[ΩGW h^2(t0)]
Log[fGW/Hz]
−6
−8
−10
−12
−14
−16
−1
0
1
2
3
4



k-reentry after CSs decay, before reheating,
$\Omega_{GW}h^2 \sim k$
m_{soft}=10TeV
m_{soft}=100TeV
m_{soft}=1000TeV
aLIGO(O2)
HLVIK
ET+2CE
($T_{rh}=10^9$GeV, n=3)
$\text{Log}[\Omega_{GW}h^2(t_0)]$
$\text{Log}[f_{GW}/\text{Hz}]$



k-reentry after reheating,
$\Omega_{GW}h^2 \sim k^3$
m_{soft}=10TeV
m_{soft}=100TeV
m_{soft}=1000TeV
aLIGO(O2)
HLVIK
ET+2CE
($T_{rh}=10^9$GeV, n=3)
$\mathrm{Log}[\Omega_{GW}h^2(t_0)]$
$\mathrm{Log}[f_{GW}/\mathrm{Hz}]$



m_soft=10TeV
m_soft=100TeV
m_soft=1000TeV
aLIGO(O2)
HLVIK
ET+2CE
(T_rh=10^8GeV, n=3)
Log[Ω_GW h^2(t_0)]
Log[f_GW/Hz]
m_soft=10TeV
m_soft=100TeV
m_soft=1000TeV
aLIGO(O2)
HLVIK
ET+2CE
(T_rh=10^9GeV, n=3)
Log[Ω_GW h^2(t_0)]
Log[f_GW/Hz]

Summary

- Inflation may constrain R-symmetry breaking scale
- Powers of spurion of R-symmetry breaking may explain various dimensionful parameters in super potential
- When considering $\not{R}$ -induced inflation, CMB observables give $\Lambda_* \sim 10^{12}$GeV
- Model predicts $m_{soft} \sim O(m_{3/2}) \sim 100$-$1000$TeV and $T_{RH} \sim 10^9$GeV
- Cosmic string formed during reheating era can probe this parameters → can be tested by ET+2CE