DETERMINATION OF THE INFLATIONARY PARAMETERS BY THE DIRECT DETECTION OF THE PRIMORDIAL GRAVITATIONAL WAVES

Ryusuke Jinno (University of Tokyo)

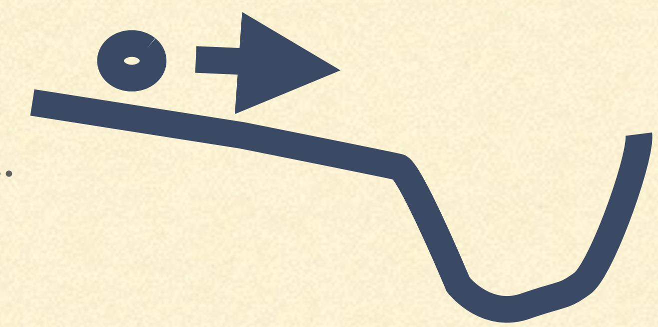
based on arXiv:1406:1666

in collaboration with
Takeo Moroi (University of Tokyo)
& Tomo Takahashi (Saga University)

PPP@Kyoto, 2014/7/29

INFLATION

- Accelerating expansion of the universe



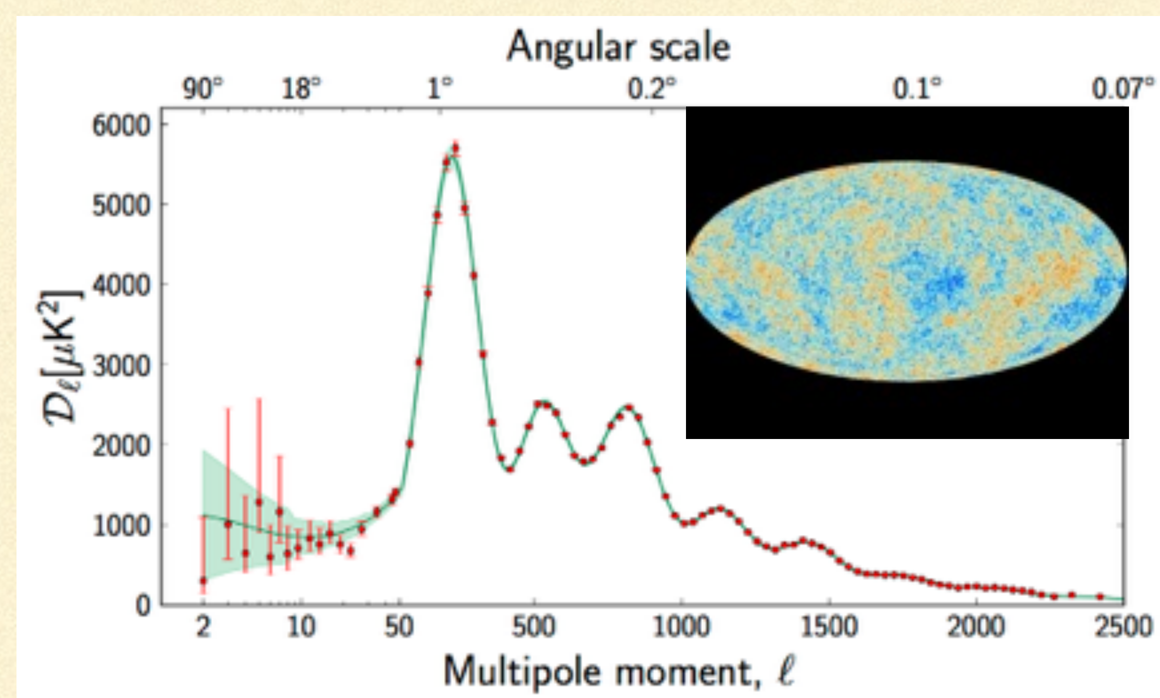
Guth '81, Sato '80, Starobimsky '80, ...

- Predicts primordial scalar & tensor fluctuations

$$\mathcal{P}_S \sim V/\epsilon \quad \mathcal{P}_T \sim V$$

- Potential & decay rate of inflaton

are still unknown

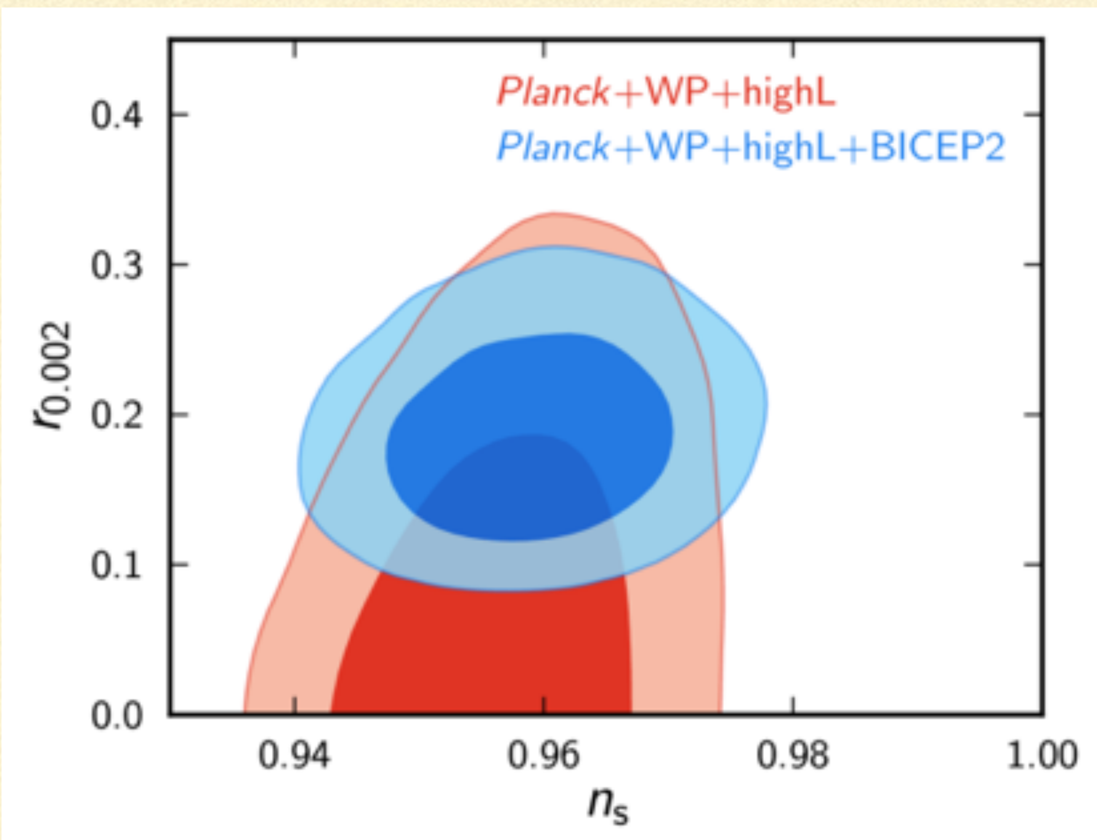


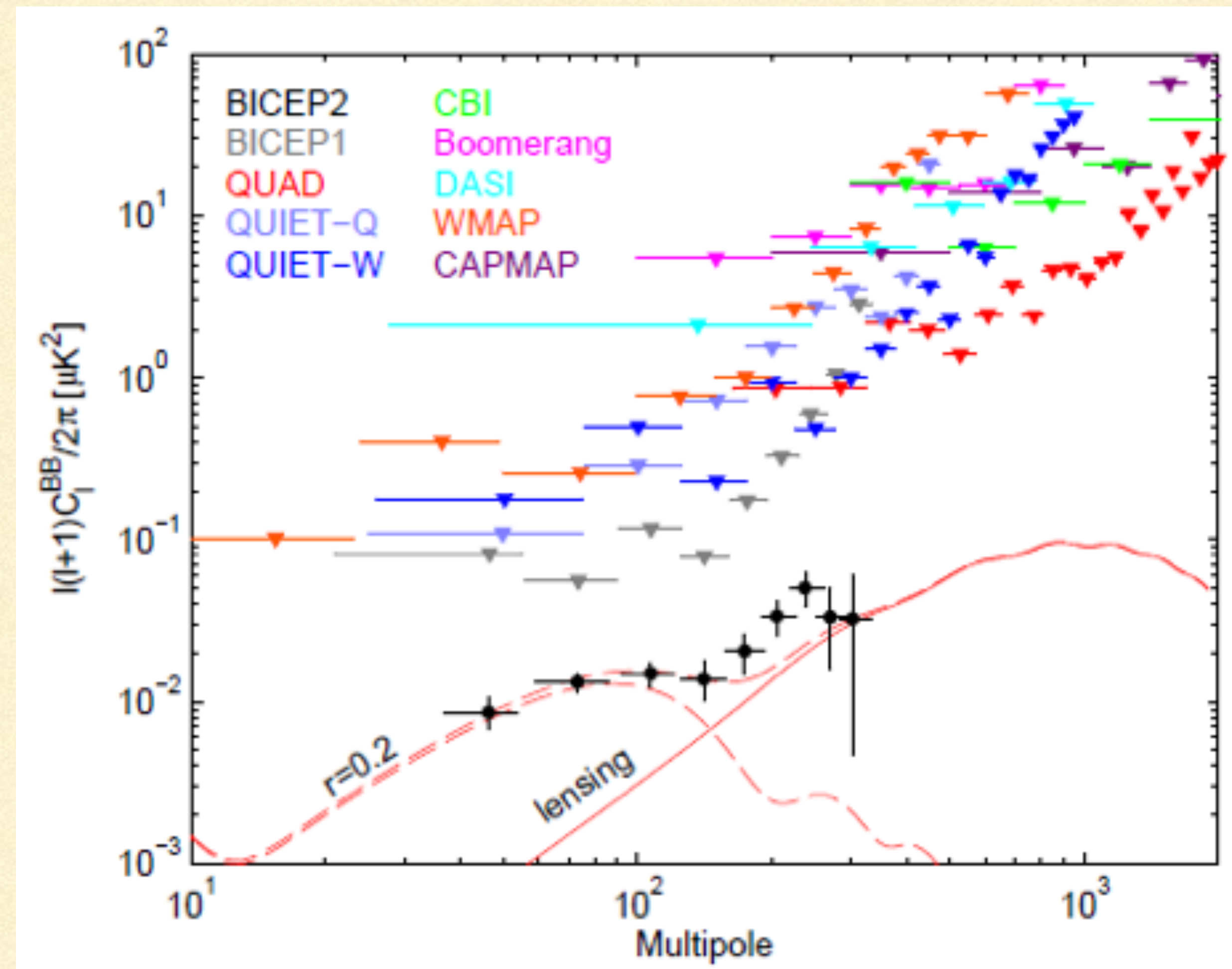
From Planck

TENSOR AMPLITUDE

- Planck & BICEP2

From BICEP2





$$r \equiv \mathcal{P}_T/\mathcal{P}_S \begin{cases} < 0.13\ (2\sigma) & \text{(Planck)} \\ = 0.2^{+0.07}_{-0.05}\ (1\sigma) & \text{(BICEP2)} \end{cases}$$

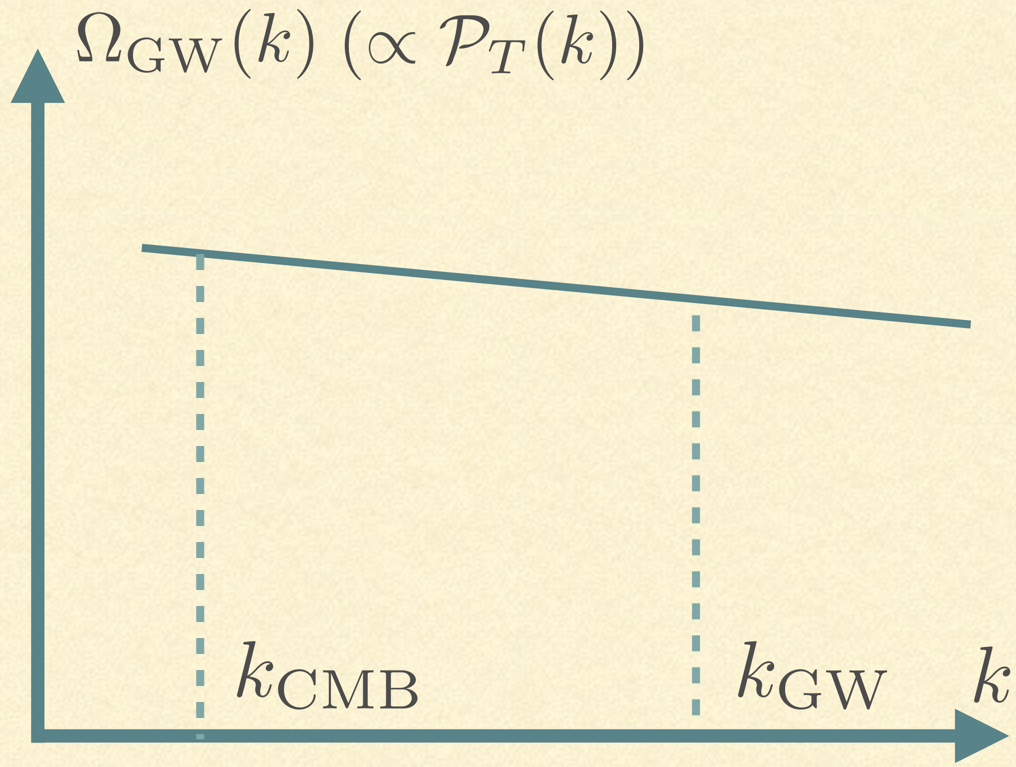
⇨ $r \sim 0.1$ may be realized

DIRECT DETECTION OF GWS

- What does $r \sim 0.1$ imply?

  Primordial tensor spectrum may also be detectable at

  $f = 2\pi k \simeq 1\mathrm{Hz}$ by space interferometers (BBO, DECIGO etc.)



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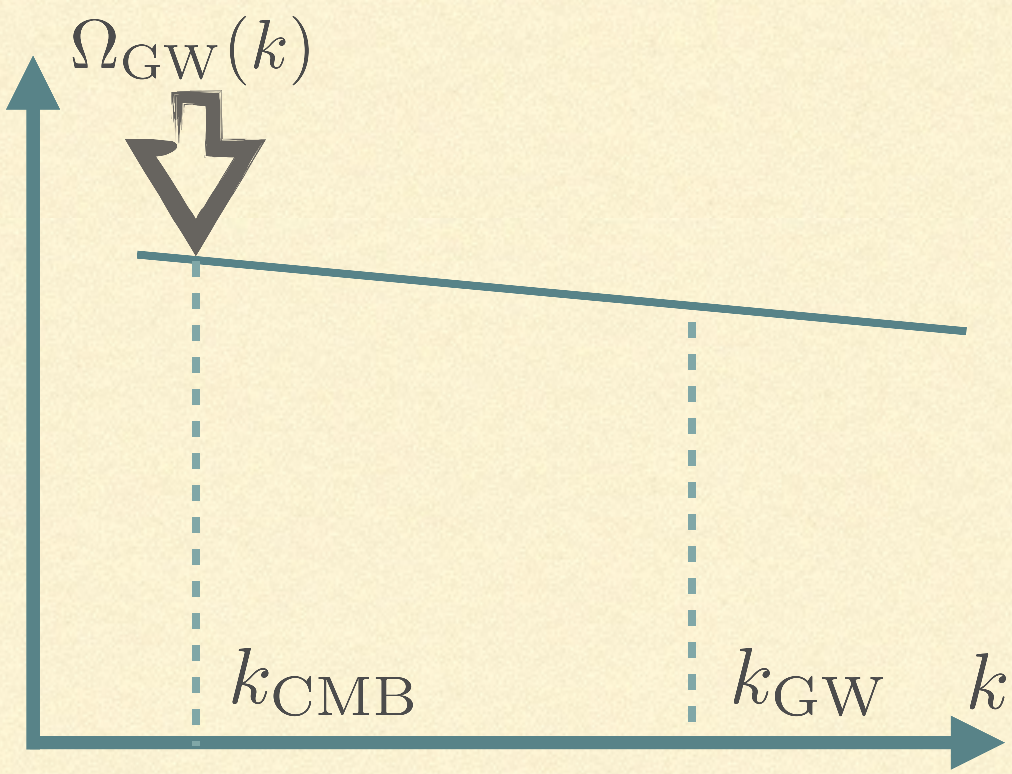

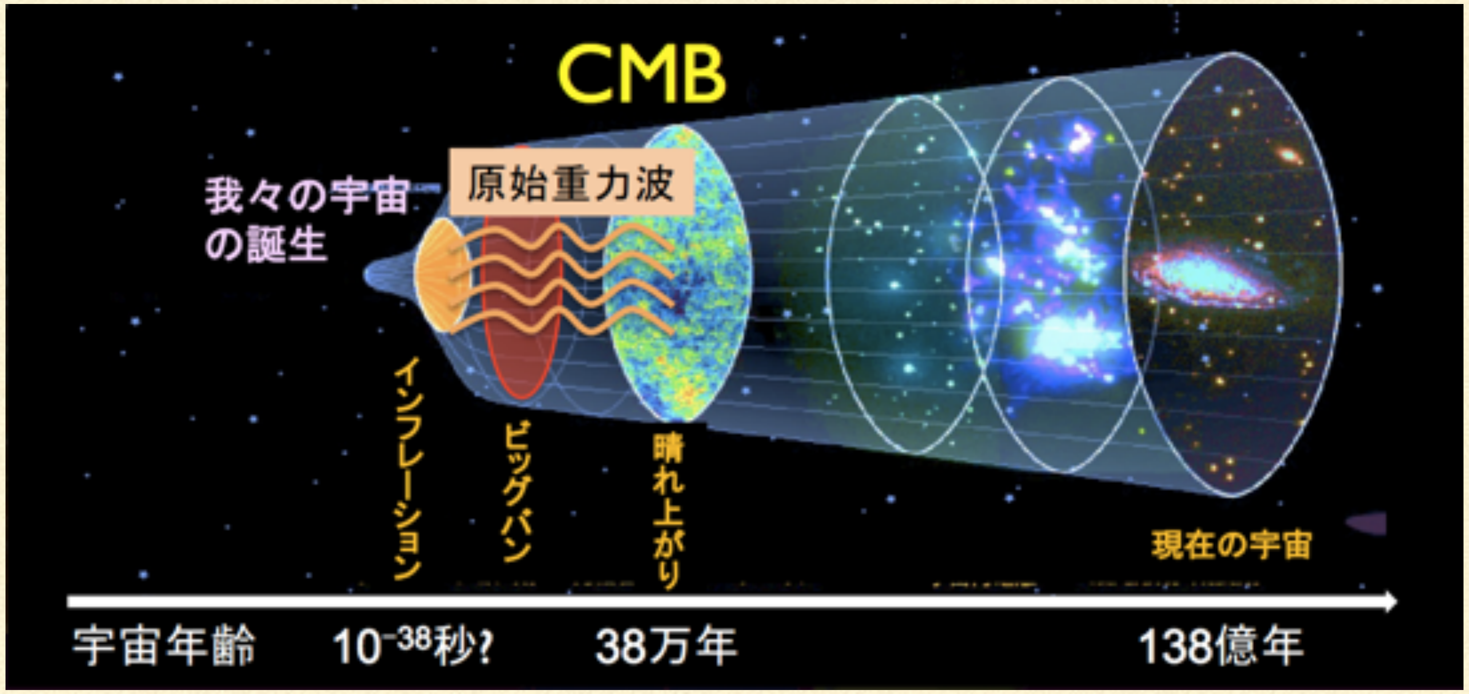

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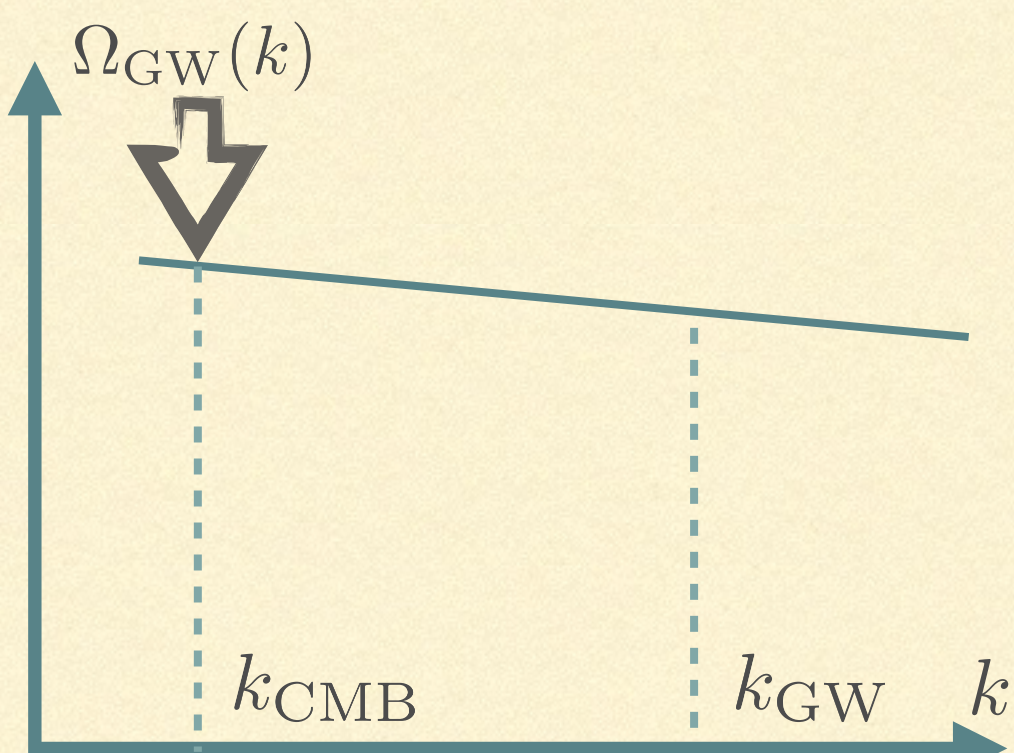

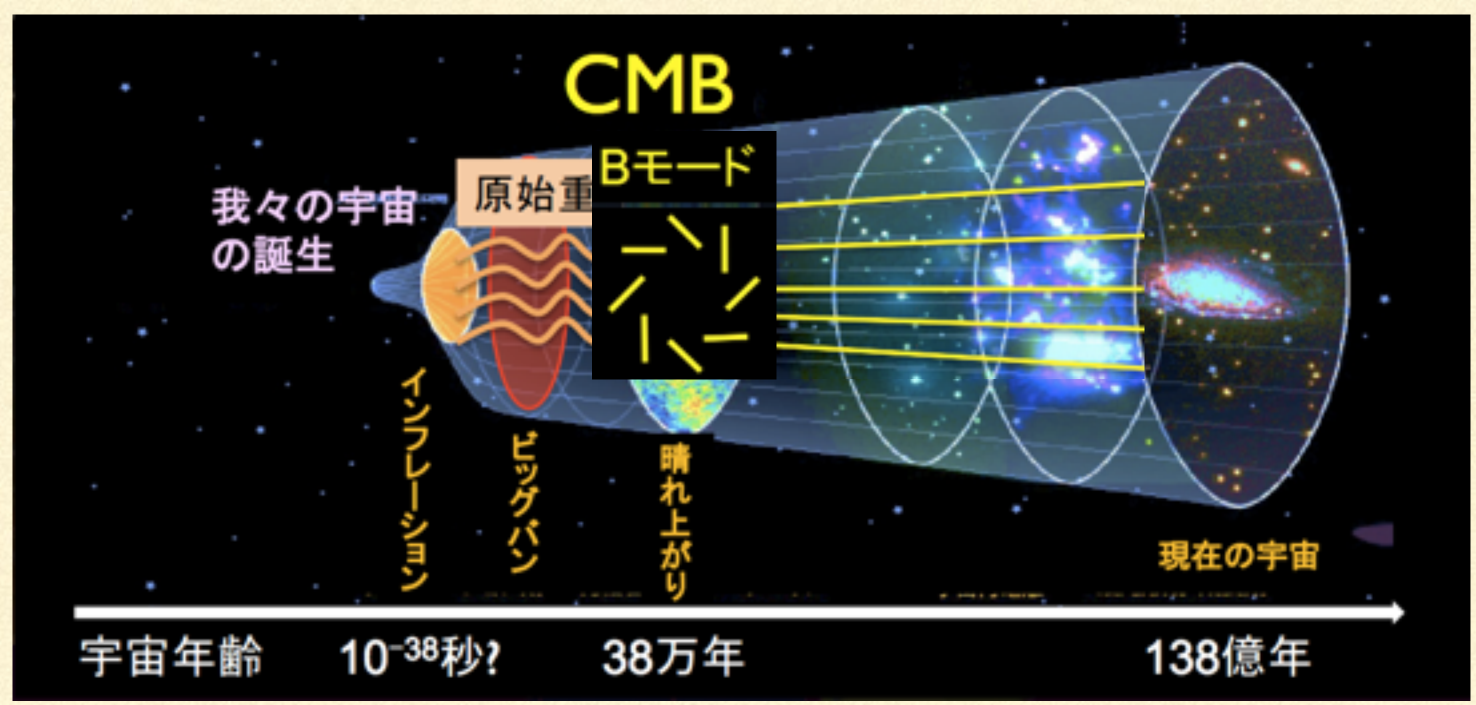

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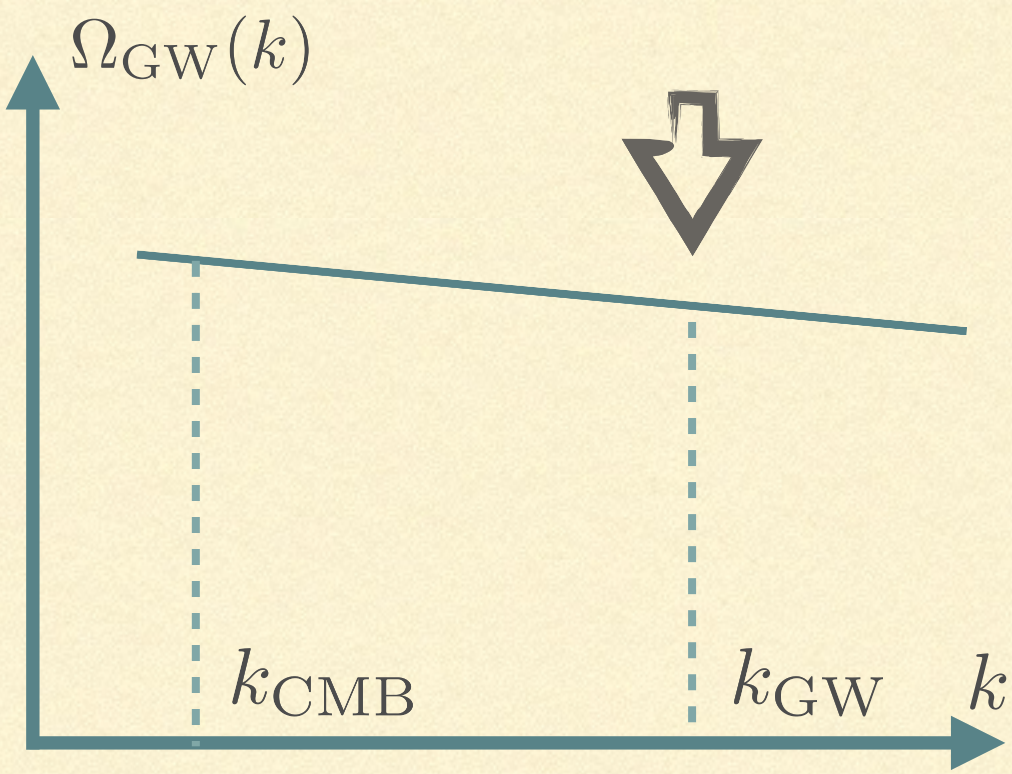
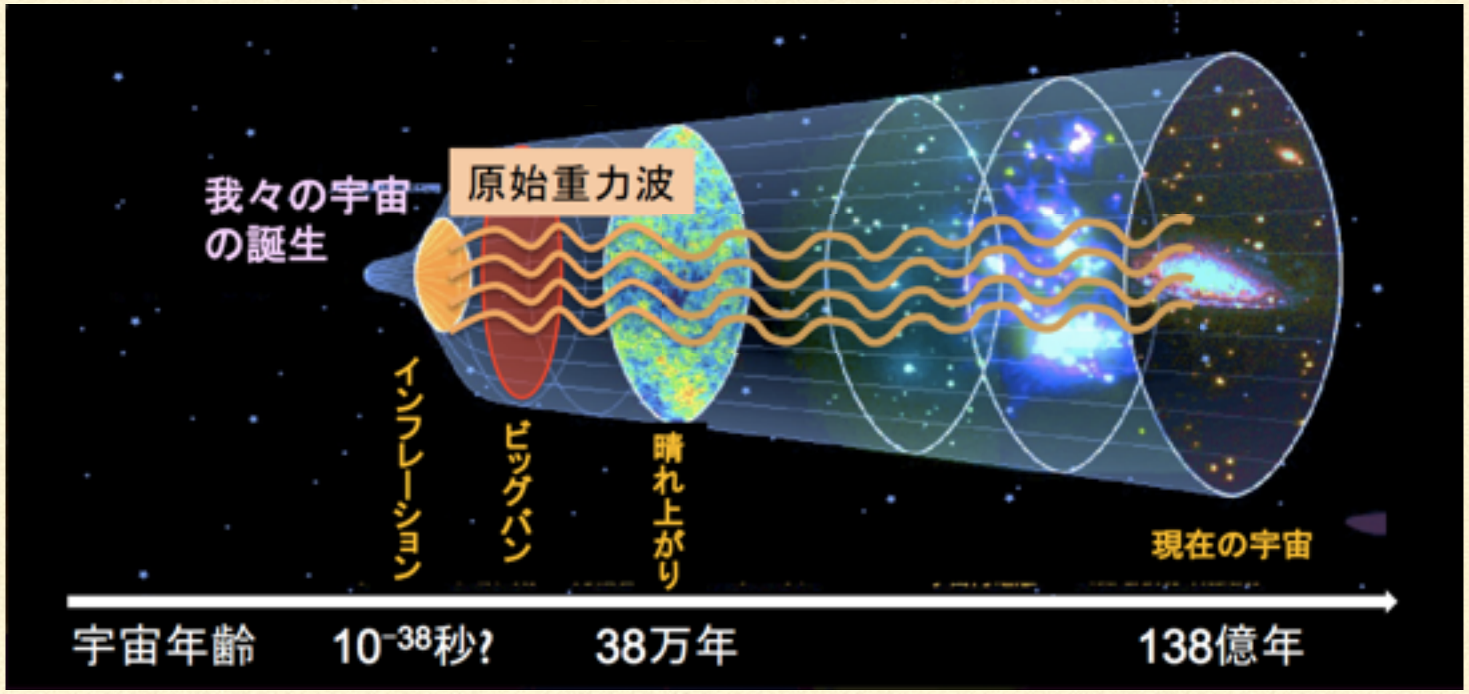




DIRECT DETECTION OF GWS

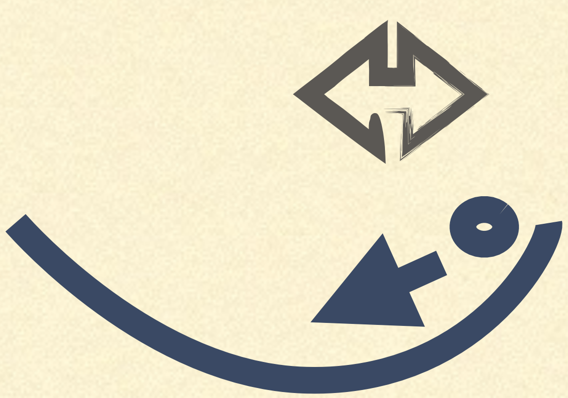
- Primordial tensor tells us about inflaton potential

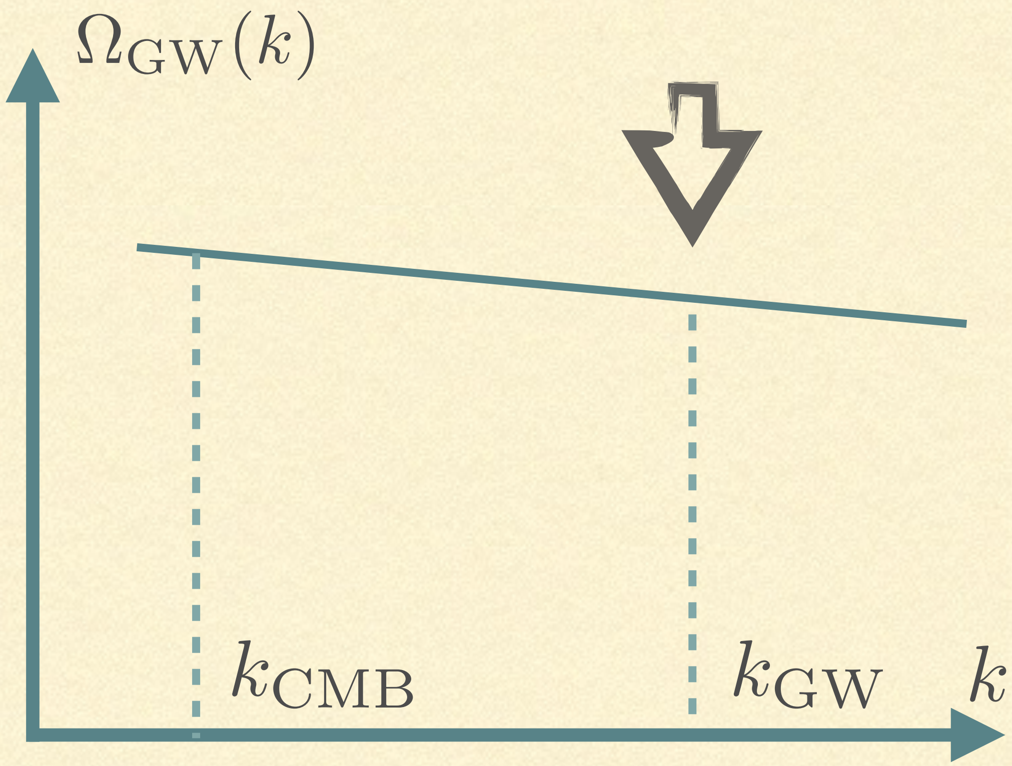
  (tensor power spectrum at 2 different scales

  → inflaton potential at 2 different inflaton values)

- Primordial tensor at GW scale

  may also tell us about reheating





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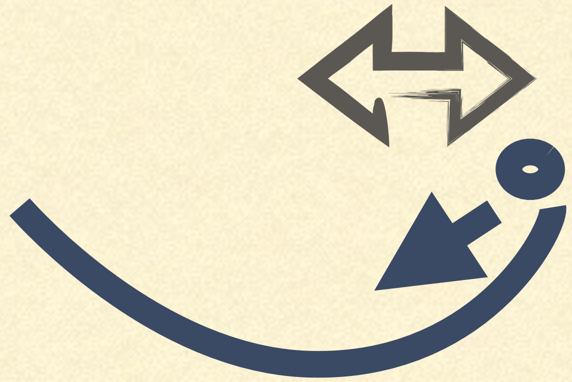

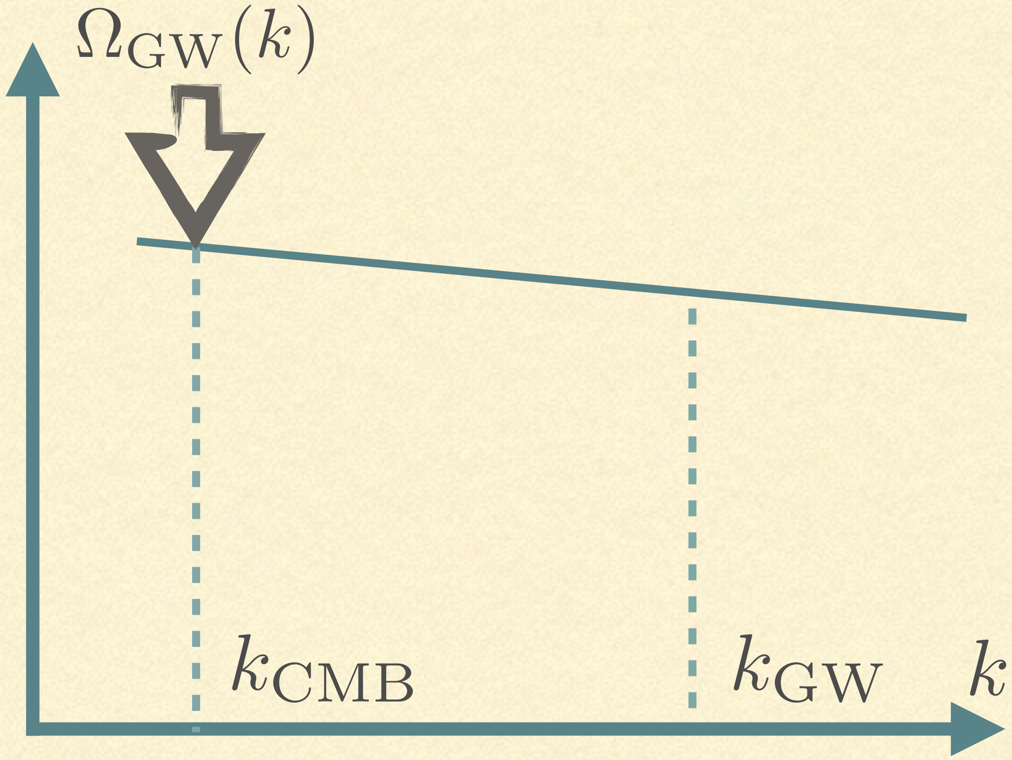

TALK PLAN

1. Introduction
2. Properties of inflationary GWs
3. χ^2 analysis
4. Result
5. Summary

PROPERTIES OF IGWS

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- Definition

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- EOM

EH action → $\ddot{h} + 3H\dot{h} + \frac{k^2}{a^2}h = 0$

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$$\mathcal{P}_{T,\mathrm{prim}}(k) = 64\pi G \left(\frac{H_{\mathrm{inf}}}{2\pi}\right)^2$$

$$\left(\langle h_{ij}(x)^2 \rangle = \int d\ln k \, \mathcal{P}_{T,\mathrm{prim}}(k)\right)$$

Proportional to the height of the inflaton potential

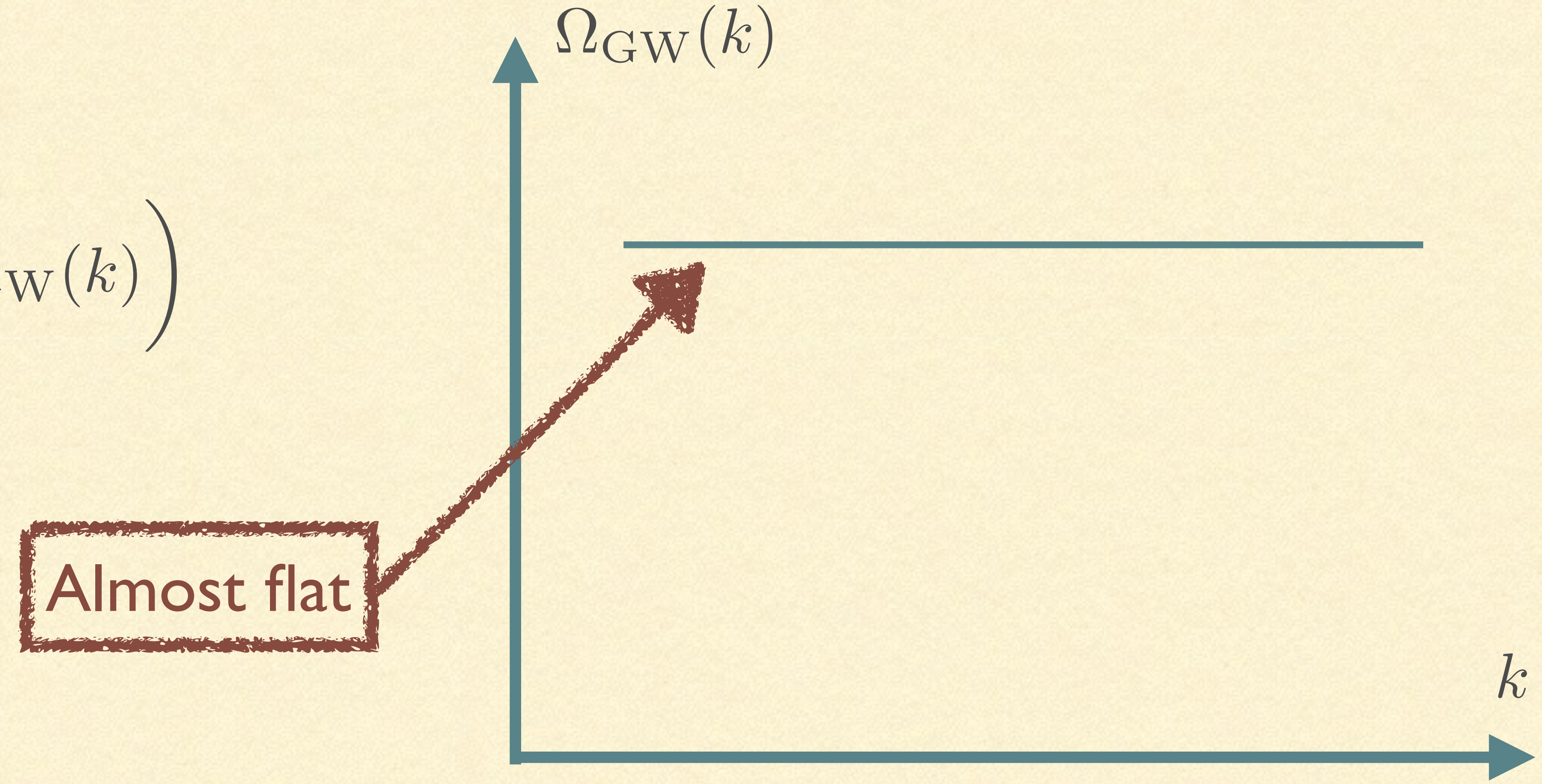
PROPERTIES OF IGWS

- Present GW amplitude

GW amplitude per logarithmic wavenumber

$$\Omega_{\rm GW}(k) \equiv \frac{\rho_{\rm GW}(k)}{\rho_{\rm cr}}$$

$$\left(\rho_{\rm GW} = \int d\ln k \; \rho_{\rm GW}(k)\right)$$



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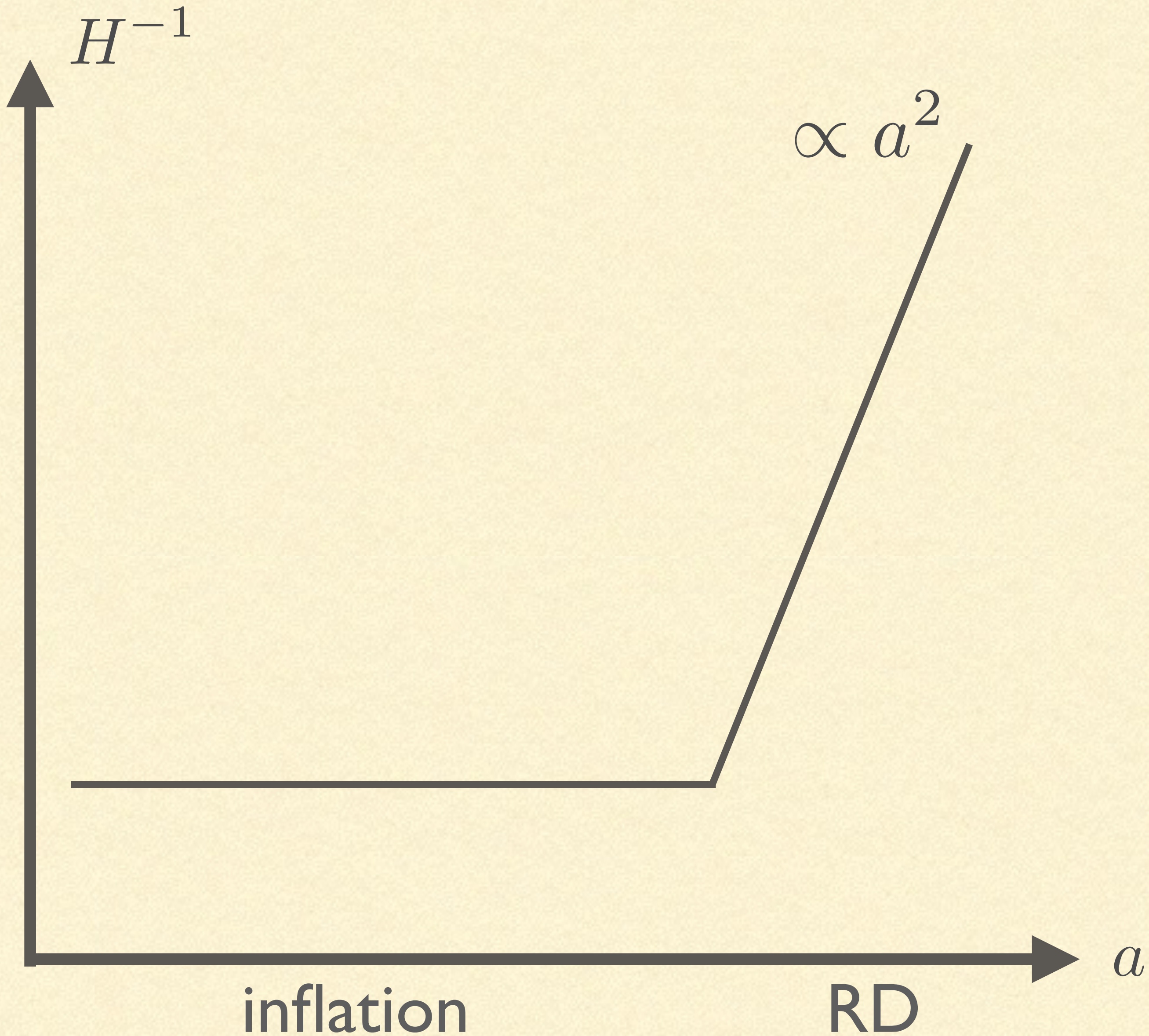

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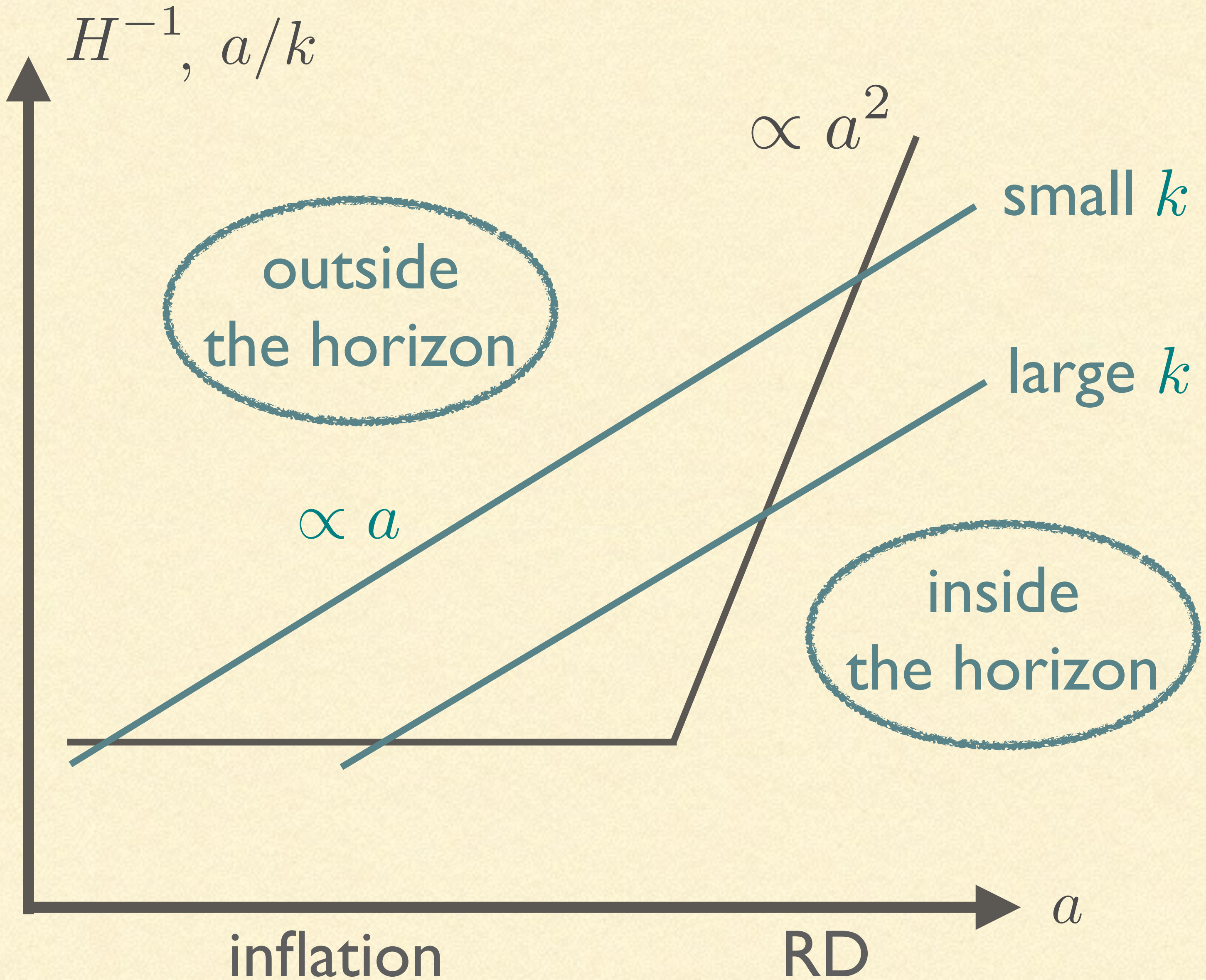

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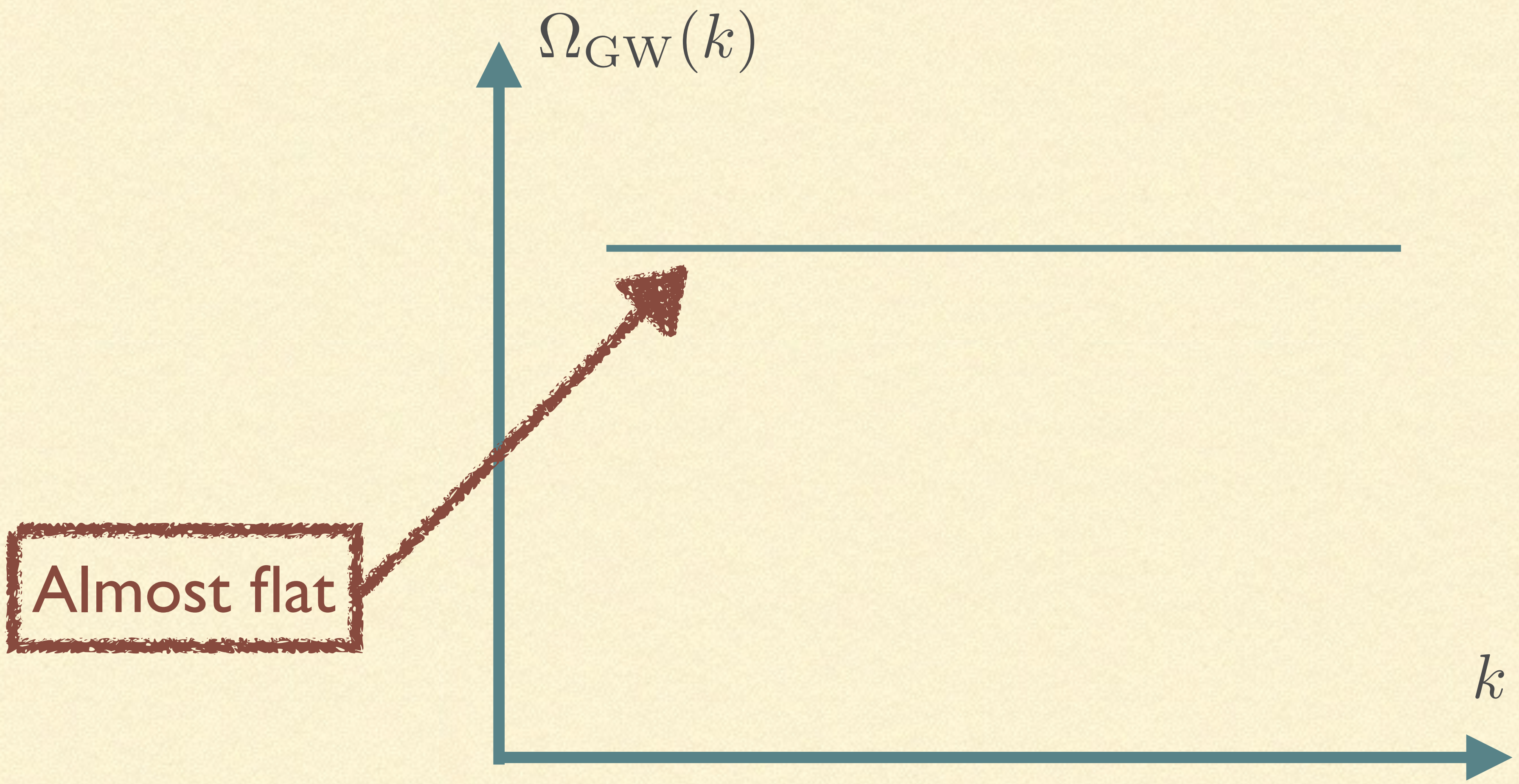

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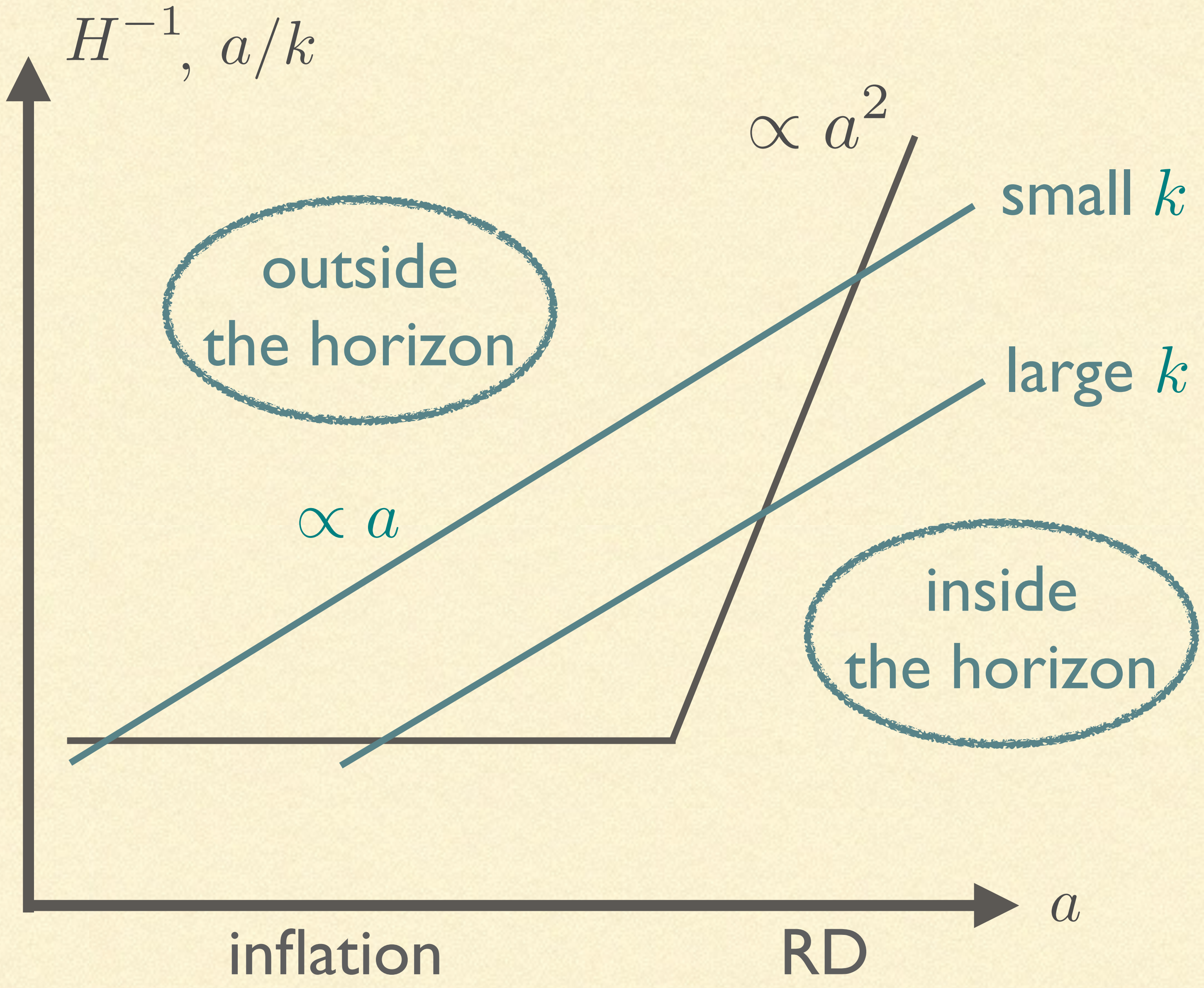

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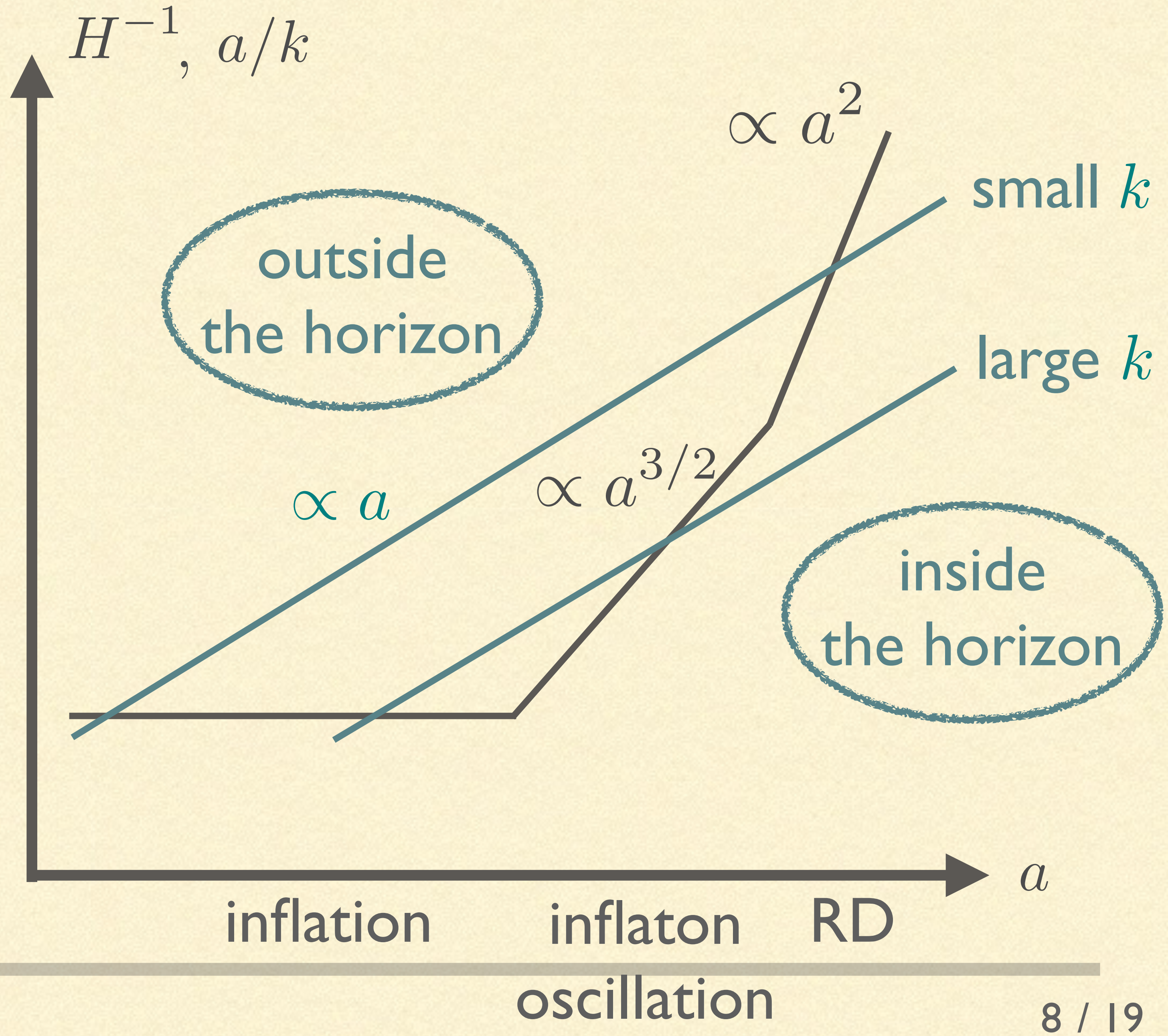

PROPERTIES OF IGWS

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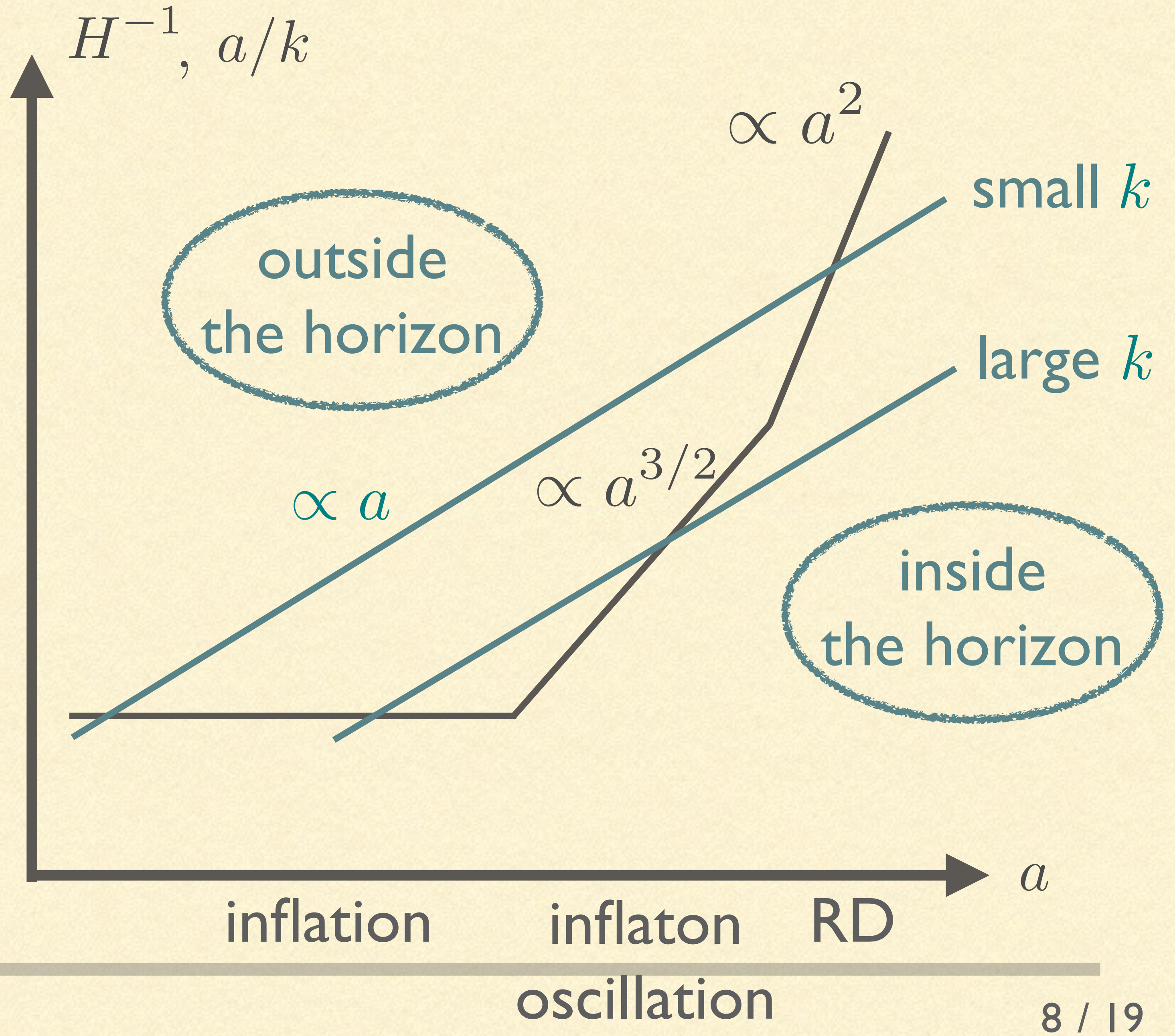
$$\ddot{h} + 3H\dot{h} + \frac{k^2}{a^2}h = 0$$

$$\rightarrow \ h \ \propto \begin{cases} a^0 & (H > k/a) \\ a^{-2} & (H < k/a) \end{cases}$$

GWs tend to decay inside the horizon



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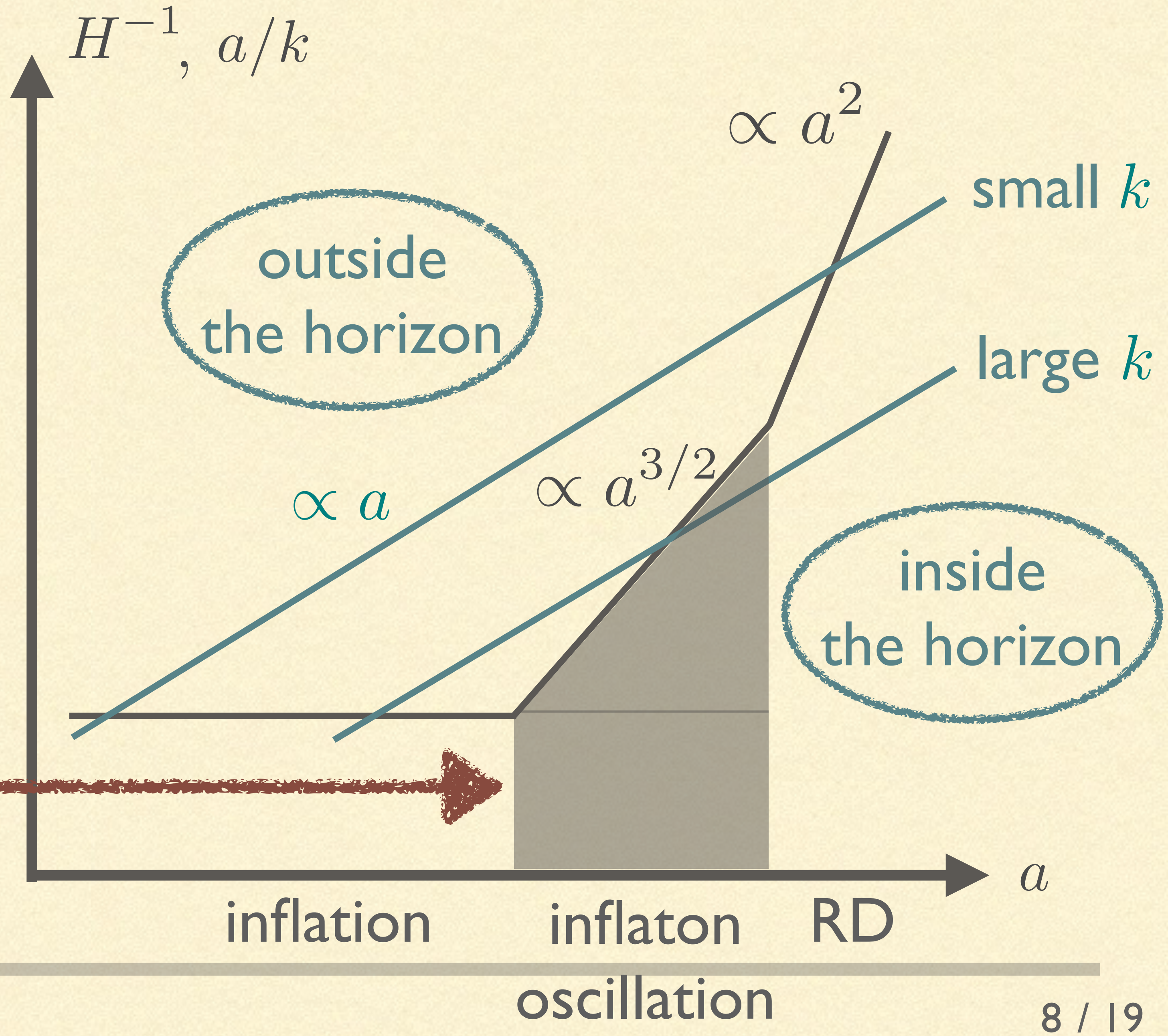
GWs tend to decay inside the horizon

GWs with larger k stay longer inside the horizon



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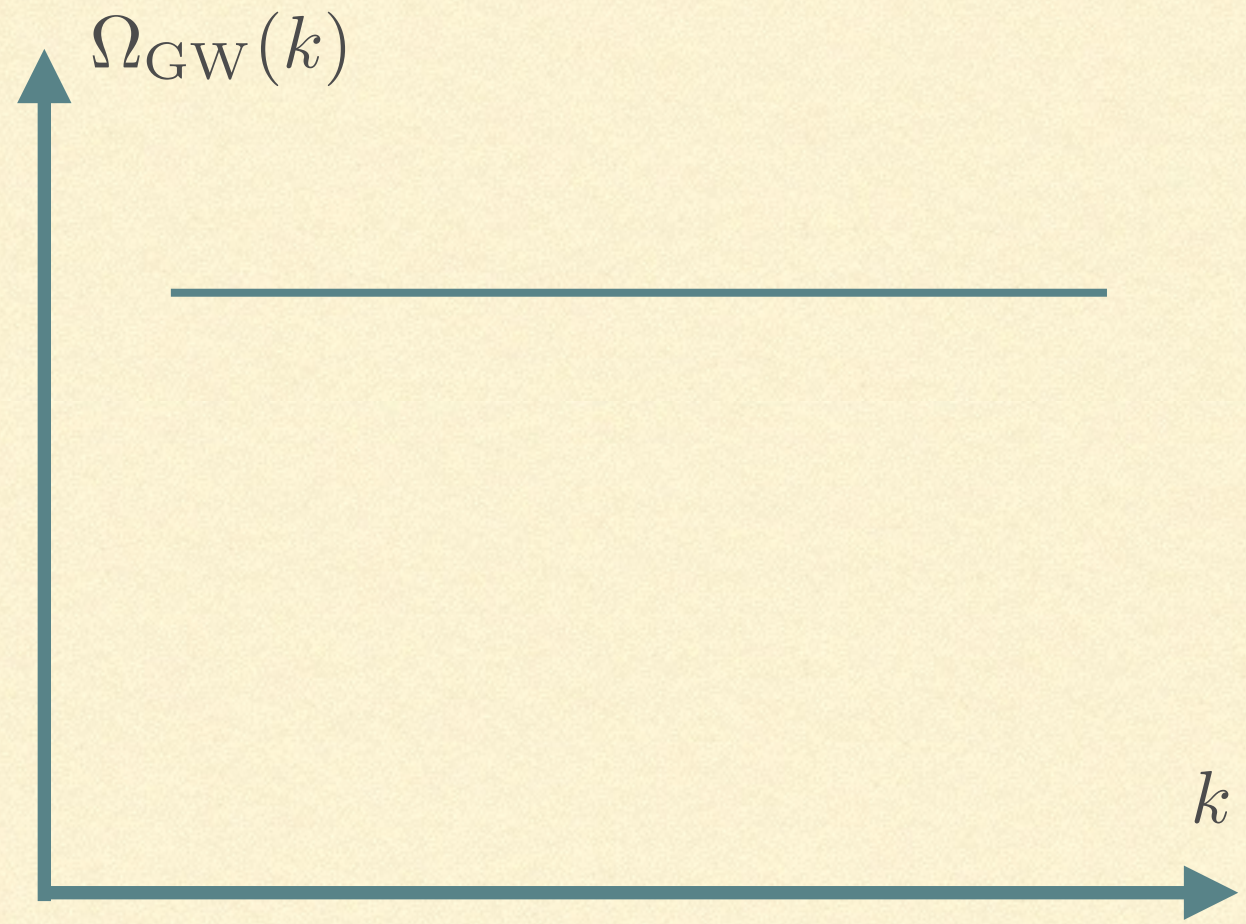

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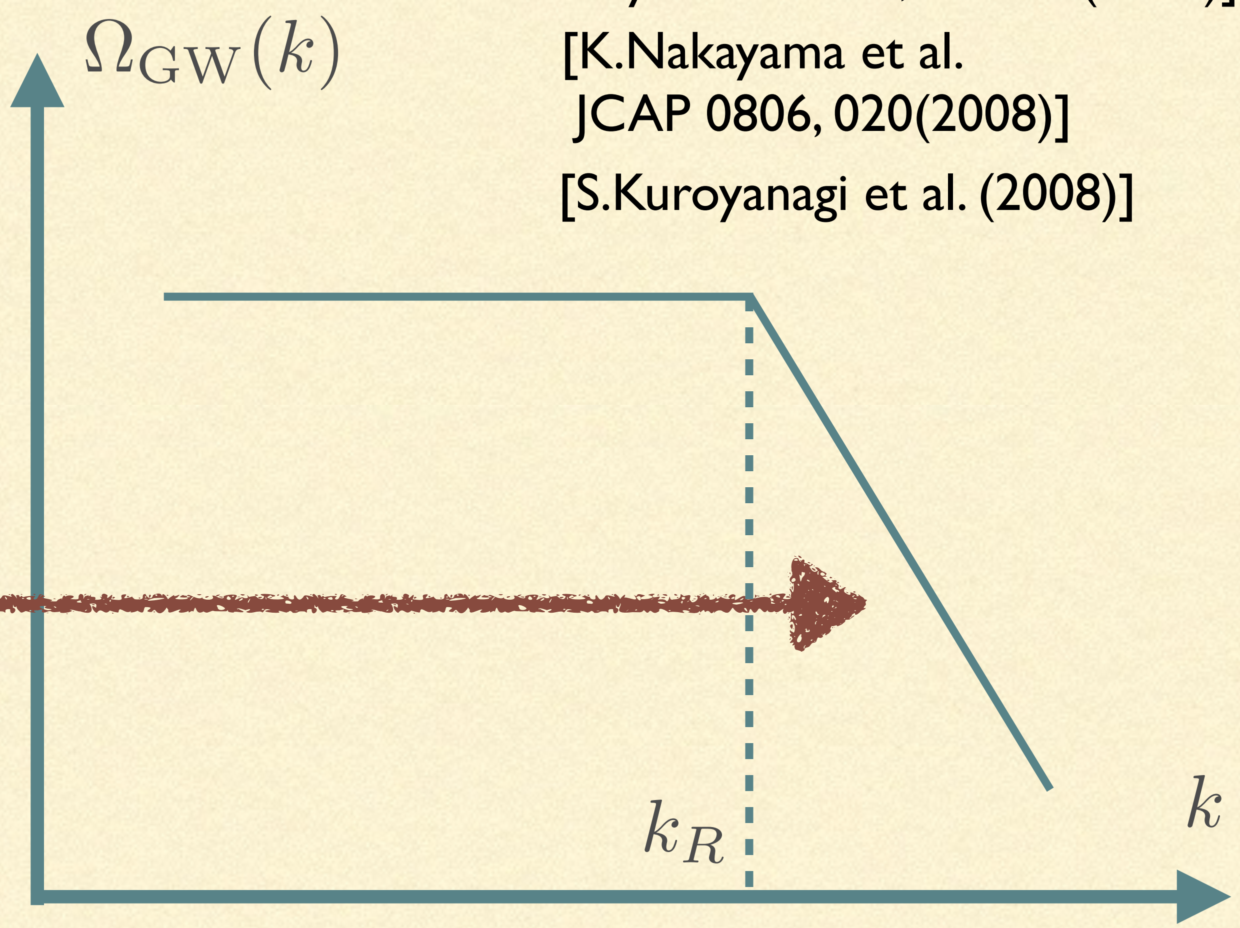
[K.Nakayama et al. Phys. Rev. D 77, 124001(2008)]
[K.Nakayama et al. JCAP 0806, 020(2008)]
[S.Kuroyanagi et al. (2008)]

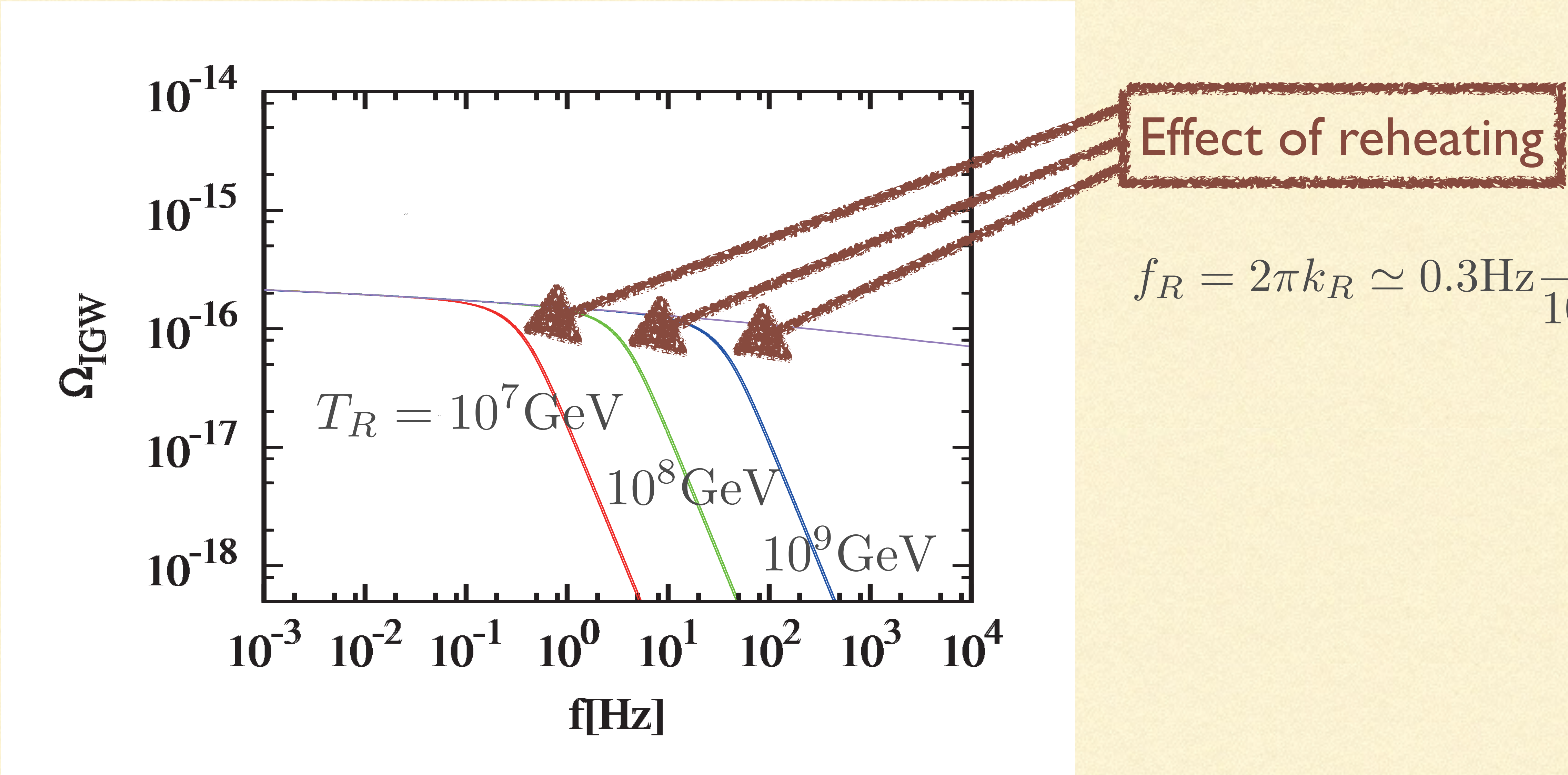


GWs with large k get suppressed

$$f_R = 2\pi k_R \simeq 0.3{\rm Hz}\frac{T_R}{10^8{\rm GeV}}$$

PROPERTIES OF IGWS

- Numerically-calculated spectrum



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χ^2 ANALYSIS

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- Noise

  BBO standard / BBO grand / ultimate DECIGO

[G. M. Harry et al.(2006)]
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The Big Bang Observer,
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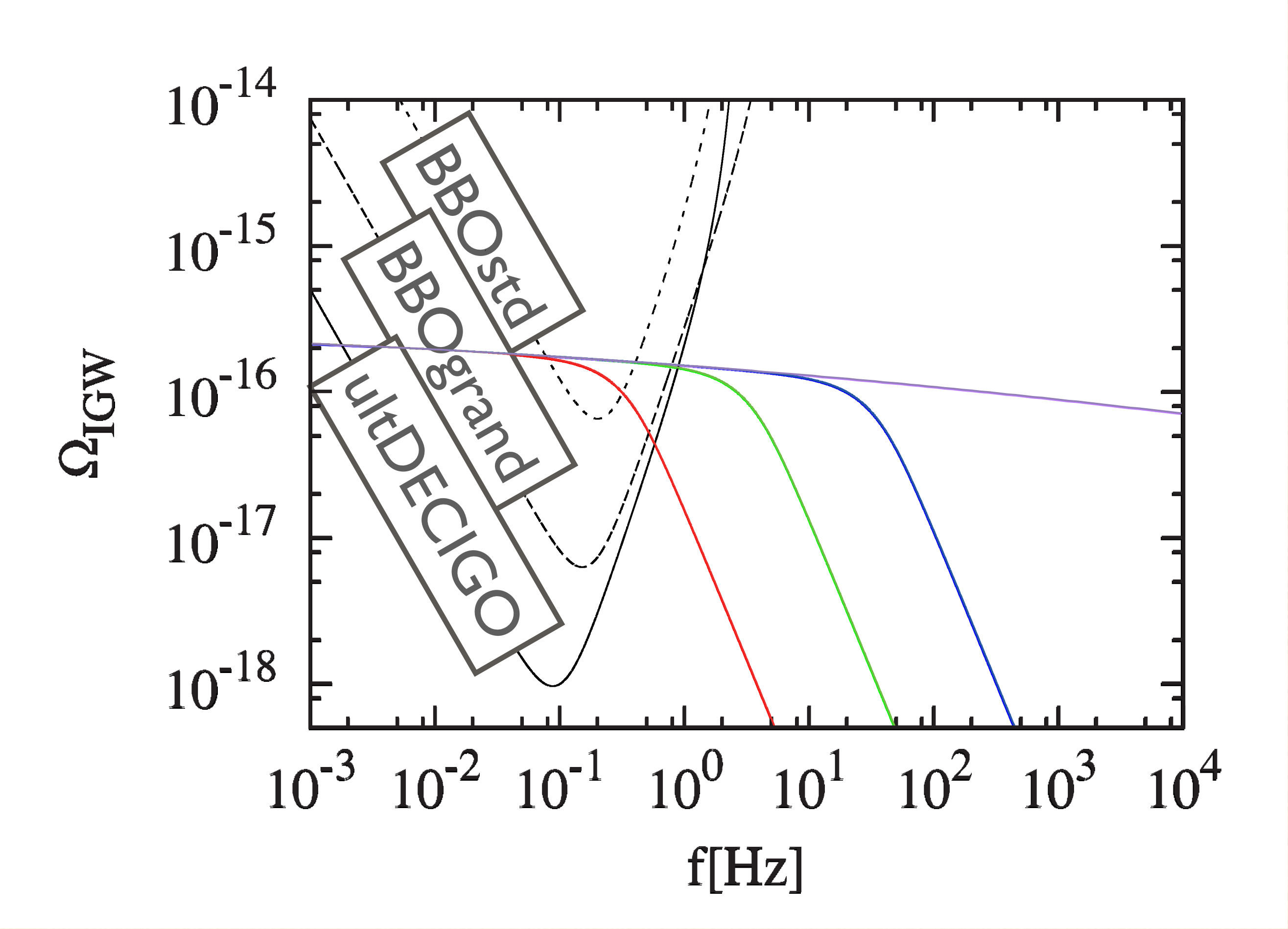

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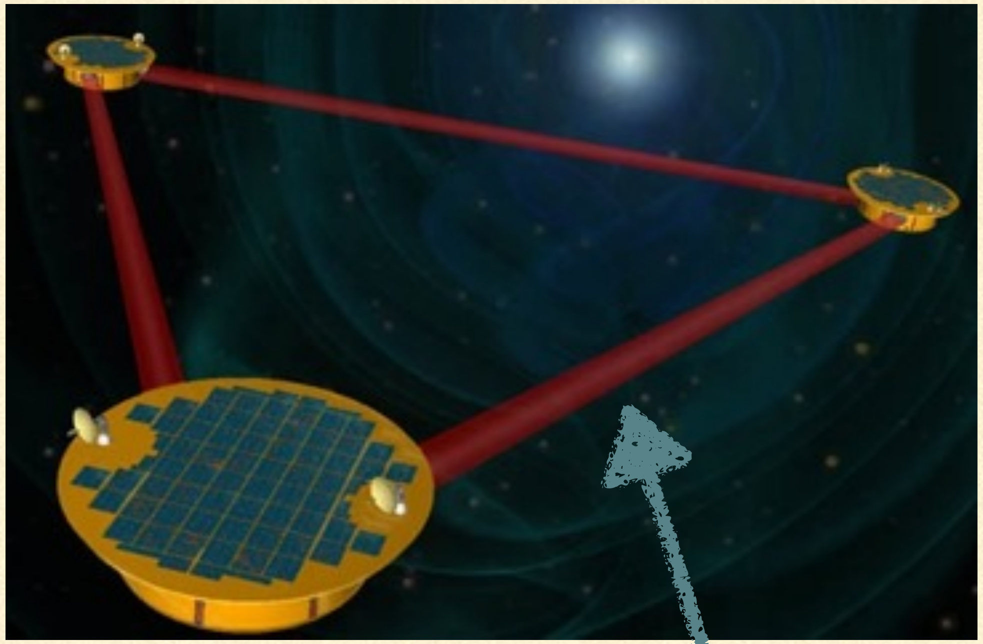
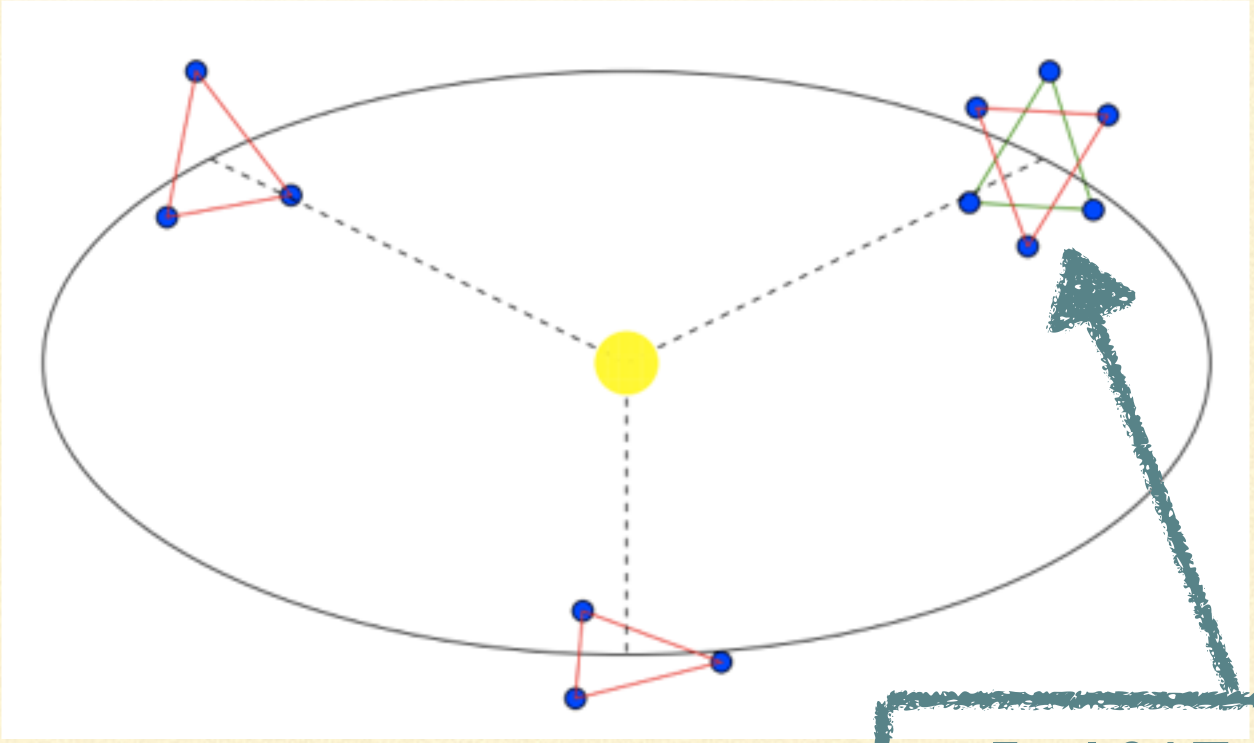
LISA [NASA's homepage]



～5×10^6m

BBO/DECIGO [J.Crowder et al.(2005)]



～5×10^7m

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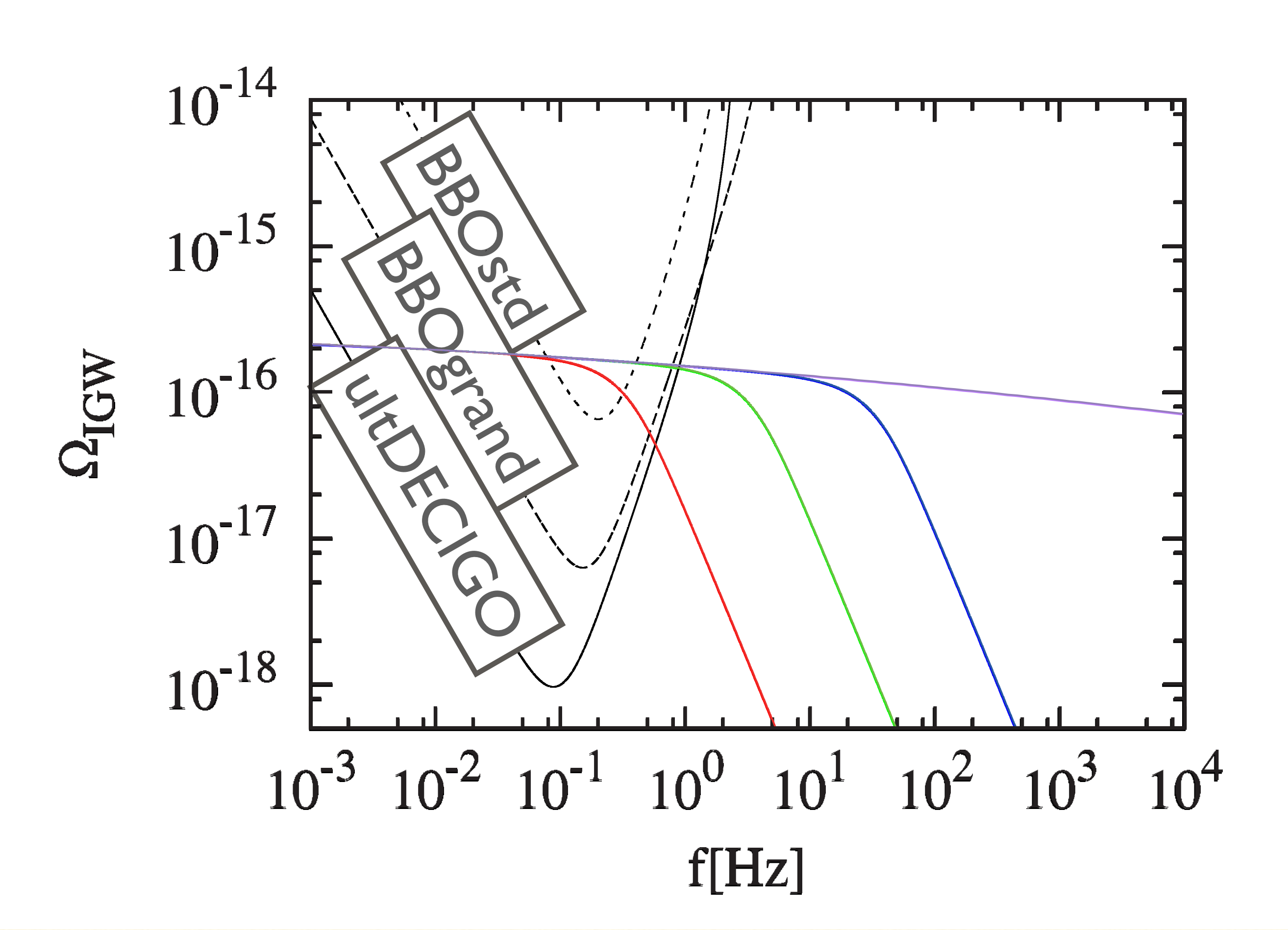

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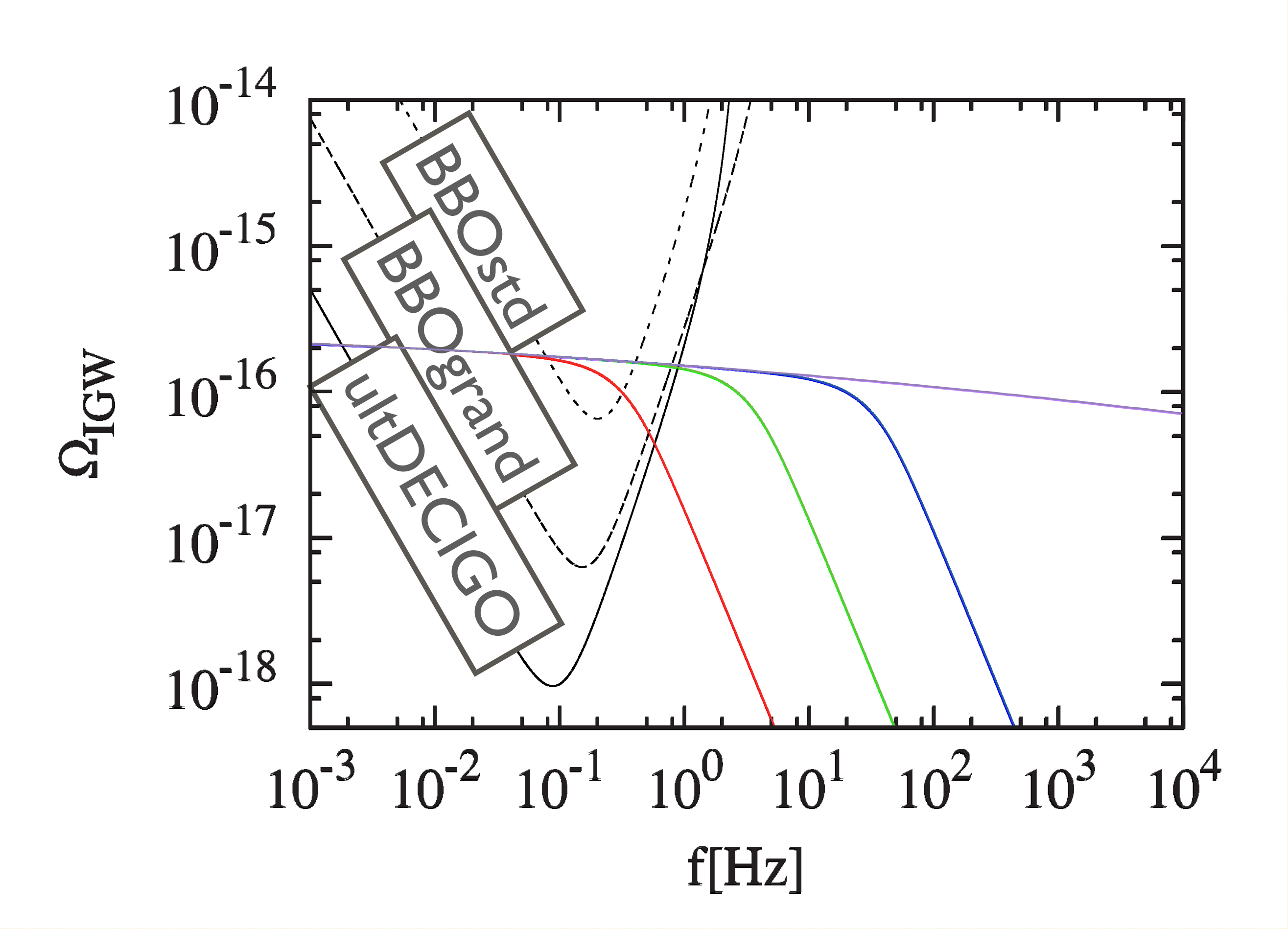


- Signal

  Fundamental parameters

  : $\Omega_{\rm GW}(f_*),\ T_R$

  Fiducial values

  : predictions of ϕ^2 chaotic inflation

  ($r \simeq 0.15$ at CMB scale)

- Expression for χ^2 [H.Kudoh et al.(2006)]

$$\chi^2 \simeq \sum_f \frac{(\Omega_{\rm GW,postulated} - \Omega_{\rm GW,true})^2}{\Delta\Omega_{\rm GW}^2}$$

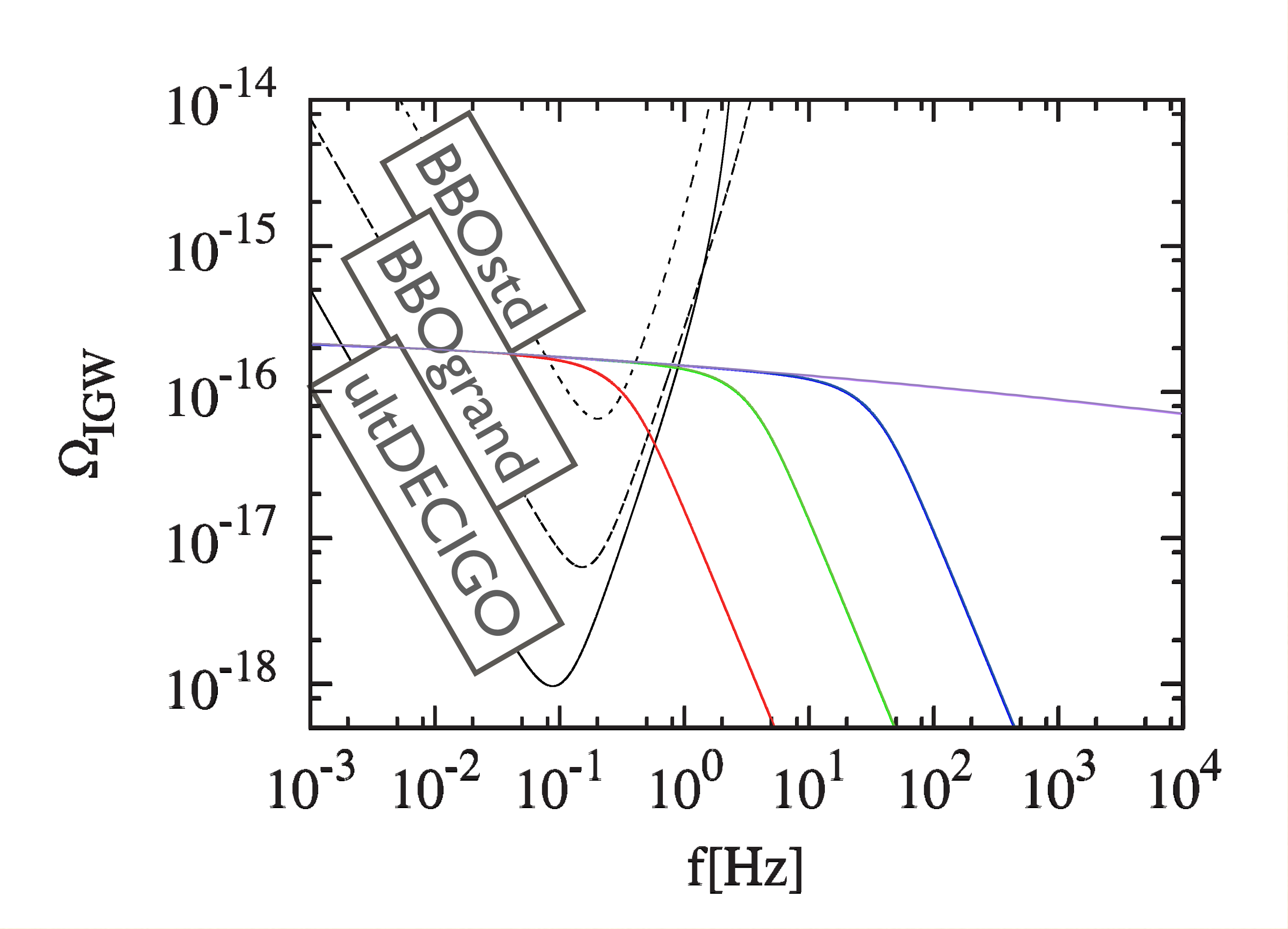
χ^2 ANALYSIS

- Beyond Fisher

$$\chi^2 \simeq \sum_f \frac{\left(\Omega_{\mathrm{GW,postulated}} - \Omega_{\mathrm{GW,true}}\right)^2}{\Delta\Omega_{\mathrm{GW}}^2} = \chi^2(\Omega_{\mathrm{GW}}(f_*), T_R)$$

For T_R direction, we do not use

Fisher approximation



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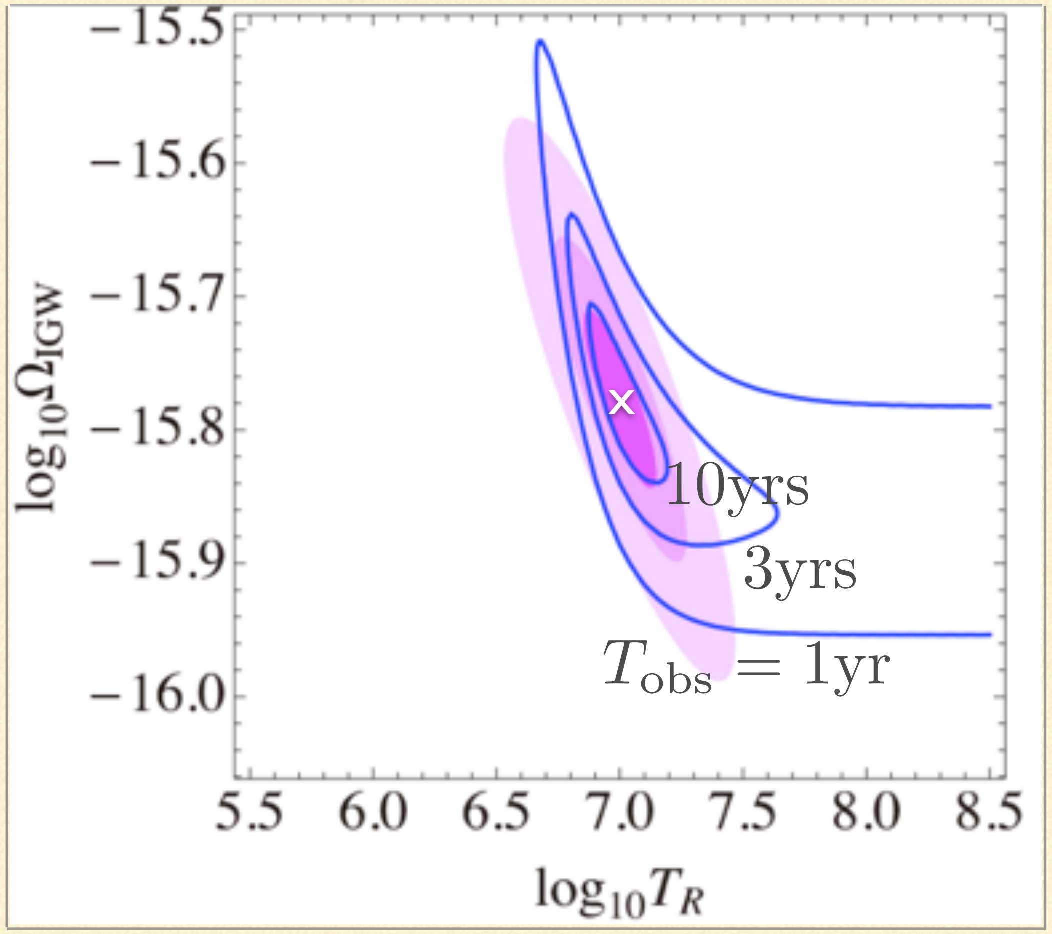
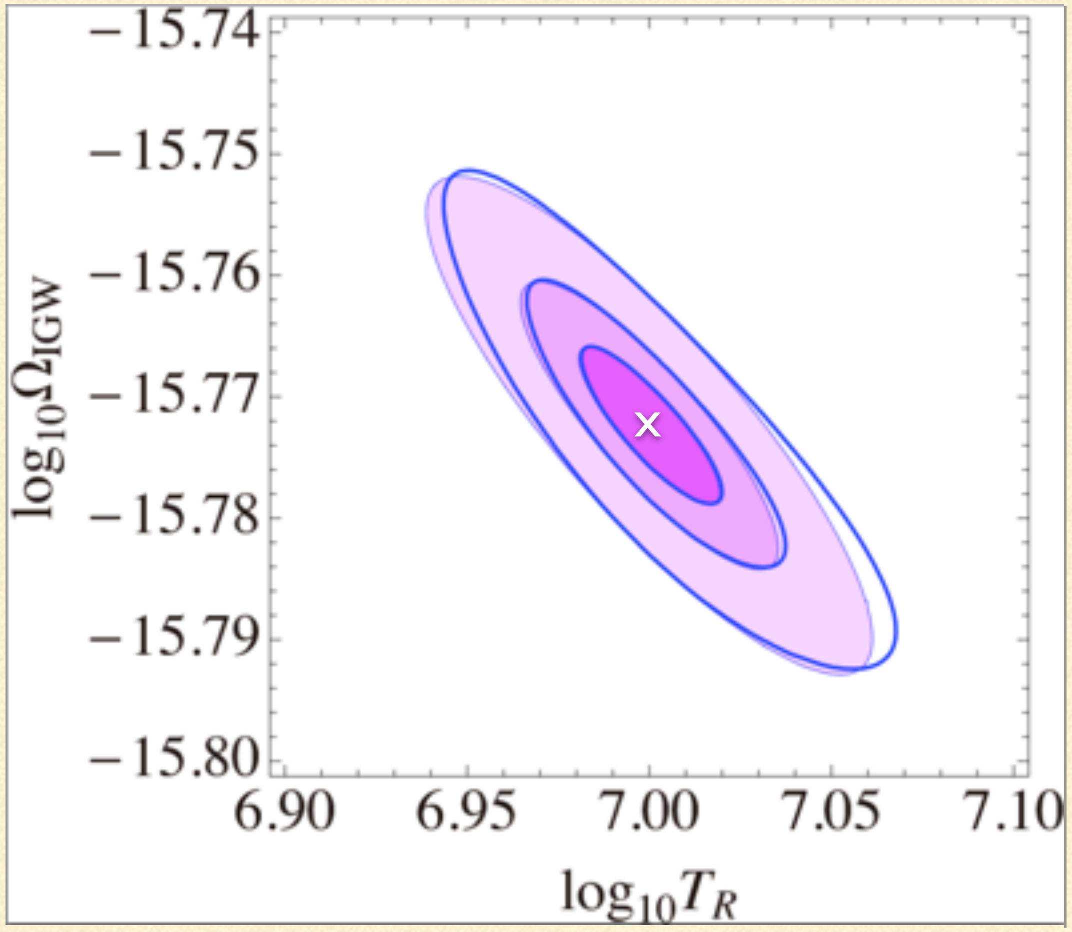
- $T_R = 10^7\,\mathrm{GeV}$ (contours for $\delta\chi^2 = 5.99$)

BBO std



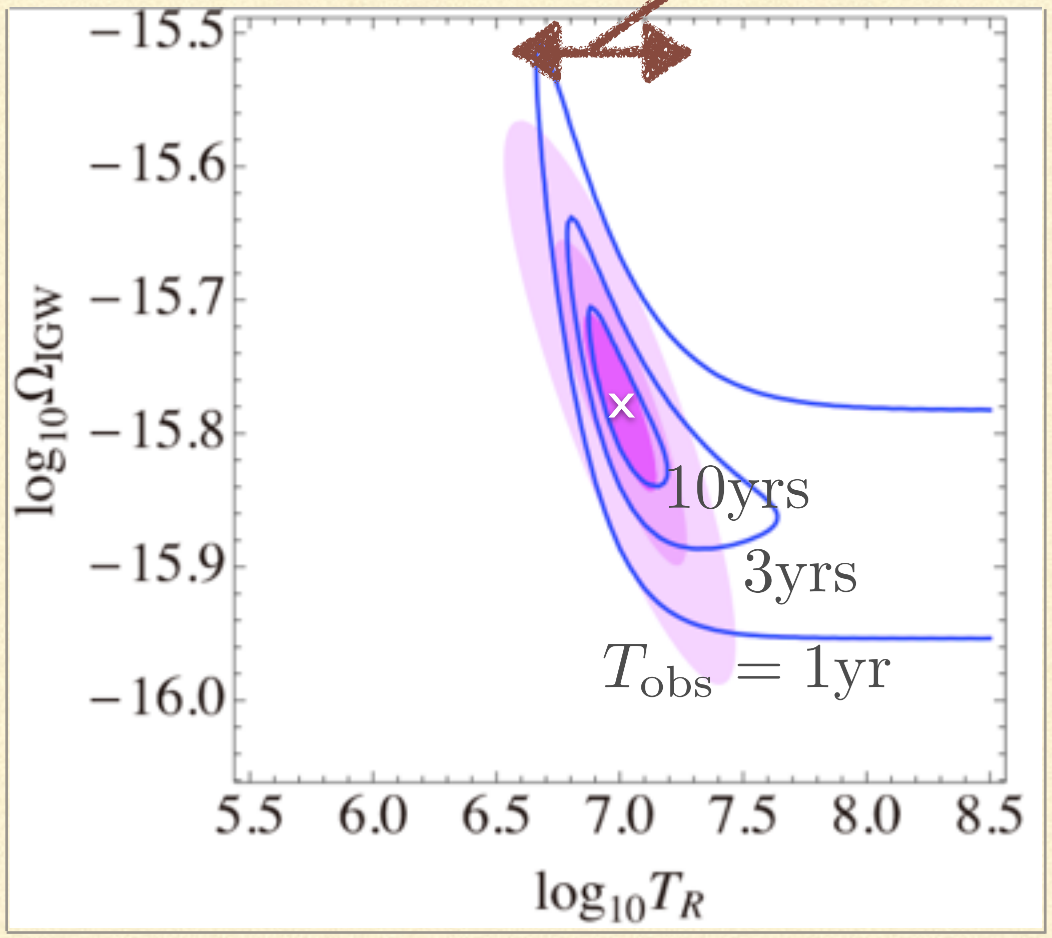
BBO grand

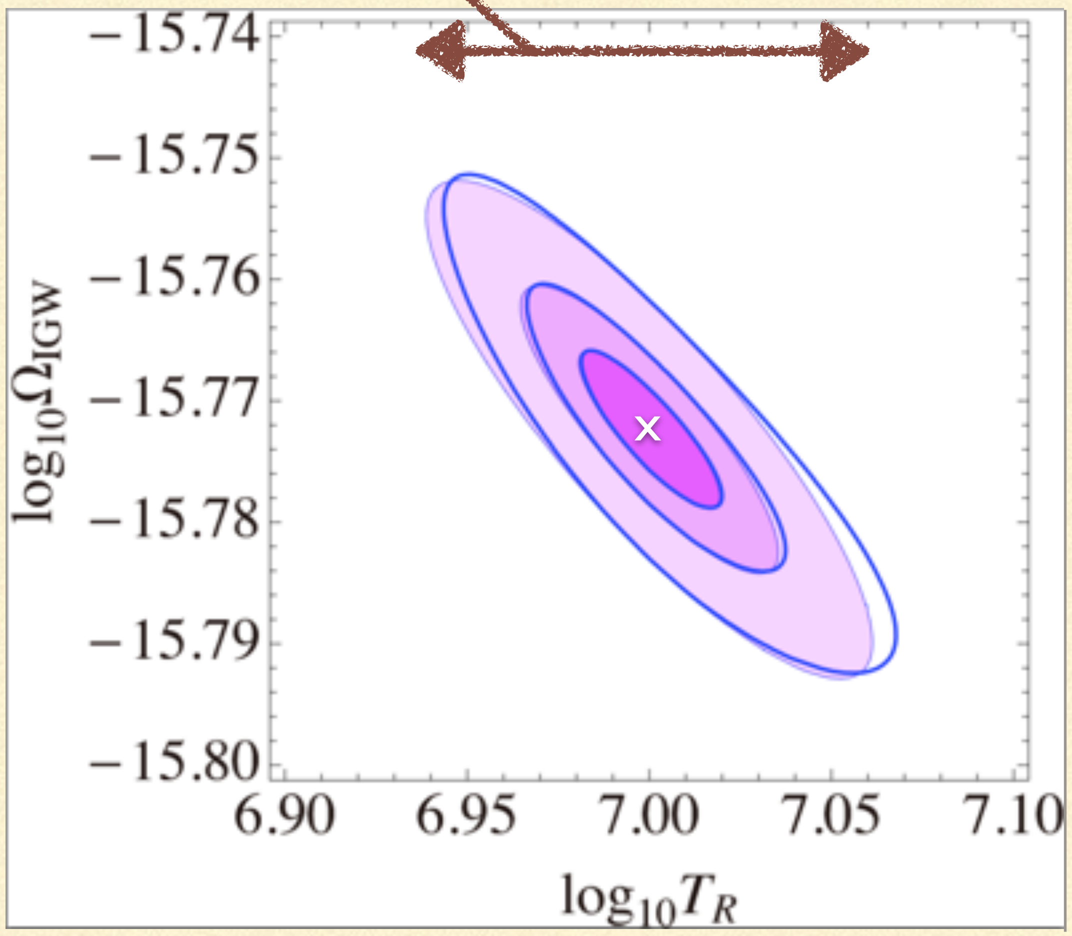


RESULT

- $T_R = 10^7\,\mathrm{GeV}$ (contours for $\delta\chi^2 = 5.99$)

BBO std T_R is well-constrained BBO grand





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- $T_R = 10^9\,\mathrm{GeV}$ (contours for $\delta\chi^2 = 5.99$)

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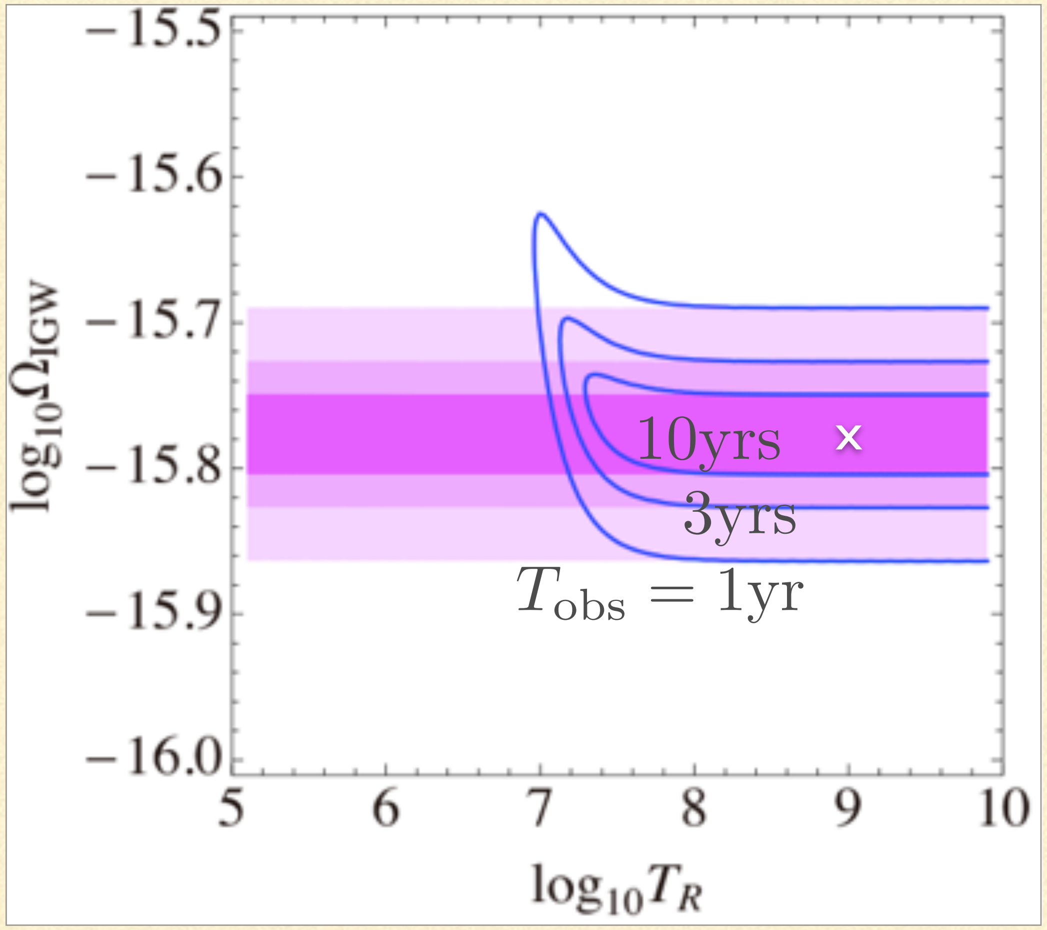
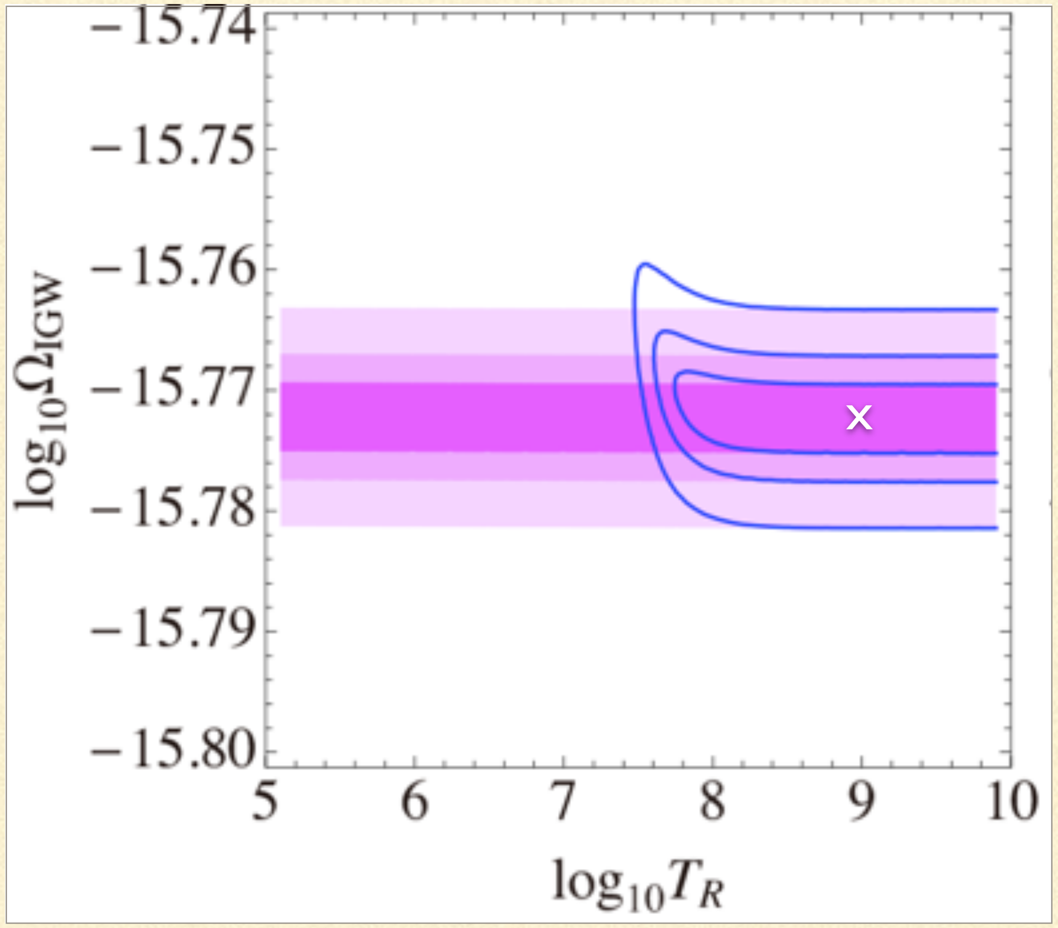


BBO grand



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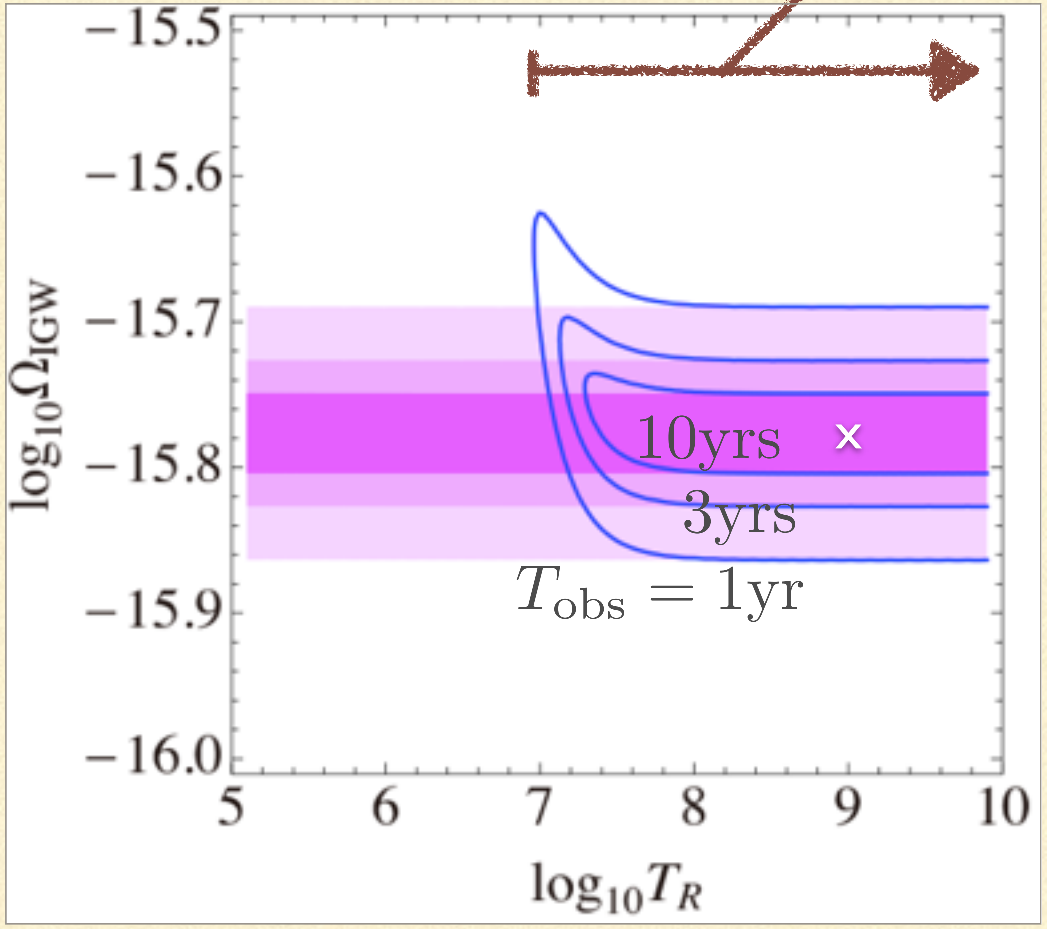
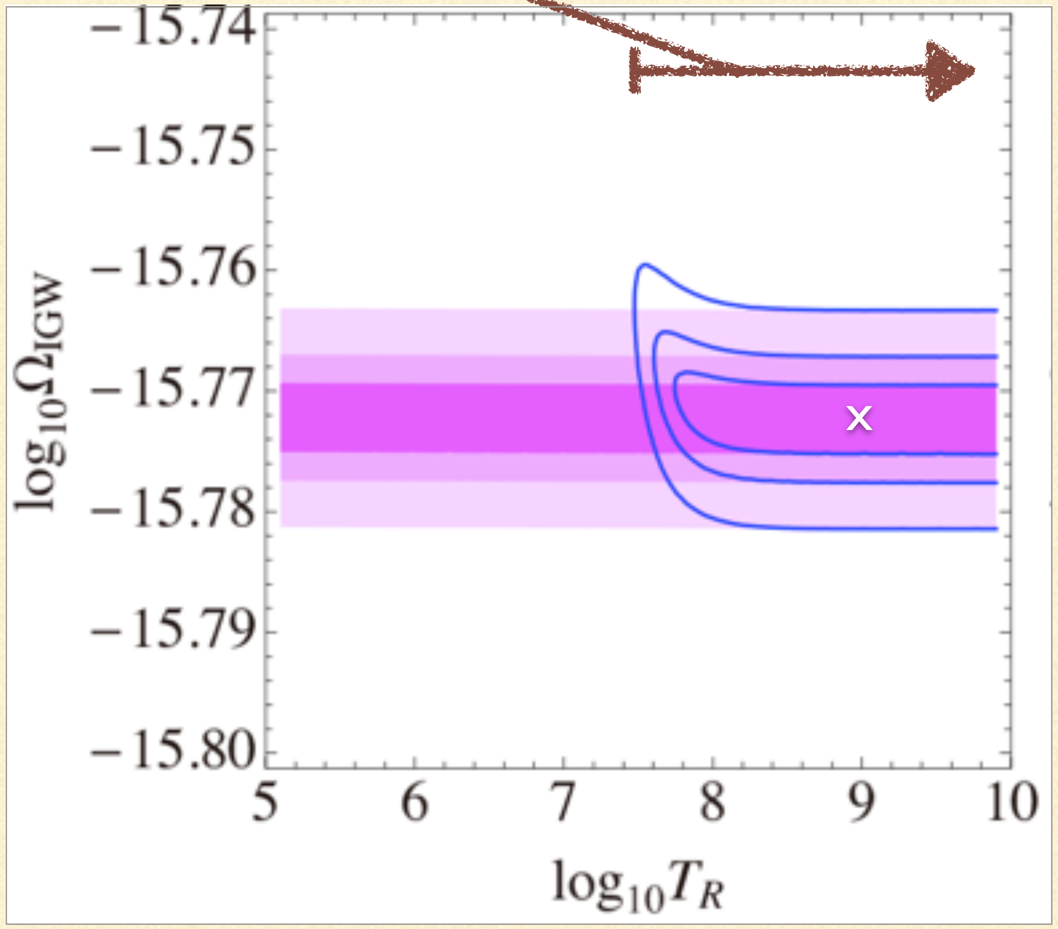
BBO std | T_R is only bounded below | BBO grand



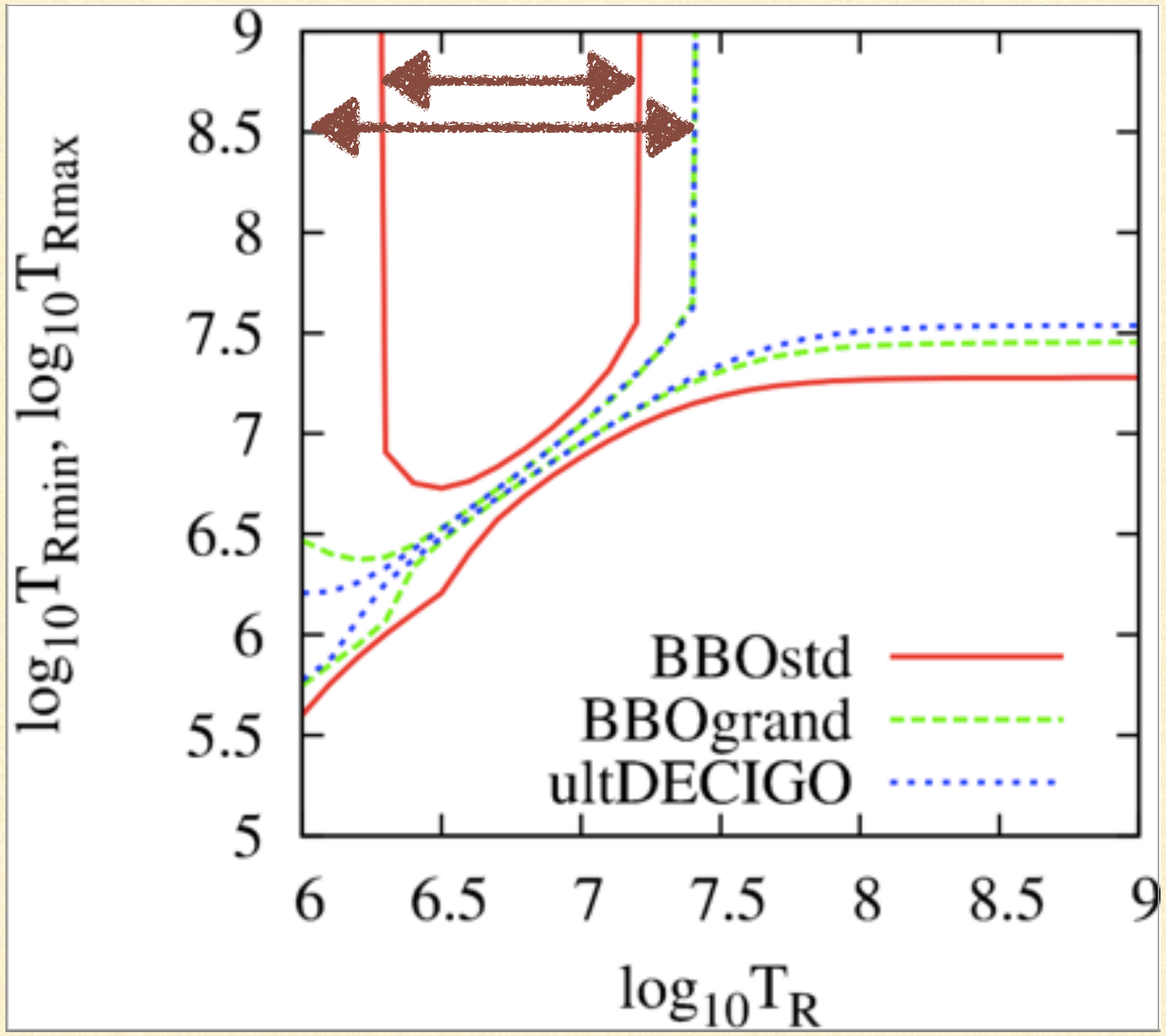


RESULT

- Upper/lower bounds on T_R

Both upper & lower bounds are obtained for

$$\begin{cases} T_R = 10^{6.3-7.2}\mathrm{GeV} \\ \quad \text{(BBO standard)} \\ T_R = 10^{6-7.4}\mathrm{GeV} \\ \quad \text{(BBO grand)} \end{cases}$$



PROPERTIES OF IGWS

- Definition

$$ds^2 = -dt^2 + a^2(\delta_{ij} + h_{ij})dx^i dx^j$$

- EOM

EH action → $\ddot{h} + 3H\dot{h} + \frac{k^2}{a^2}h = 0$

- Production by quantum fluctuation during inflation

$$\mathcal{P}_{T,\mathrm{prim}}(k) = 64\pi G\left(\frac{H_{\mathrm{inf}}}{2\pi}\right)^2$$

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Information on potential height & slow-roll

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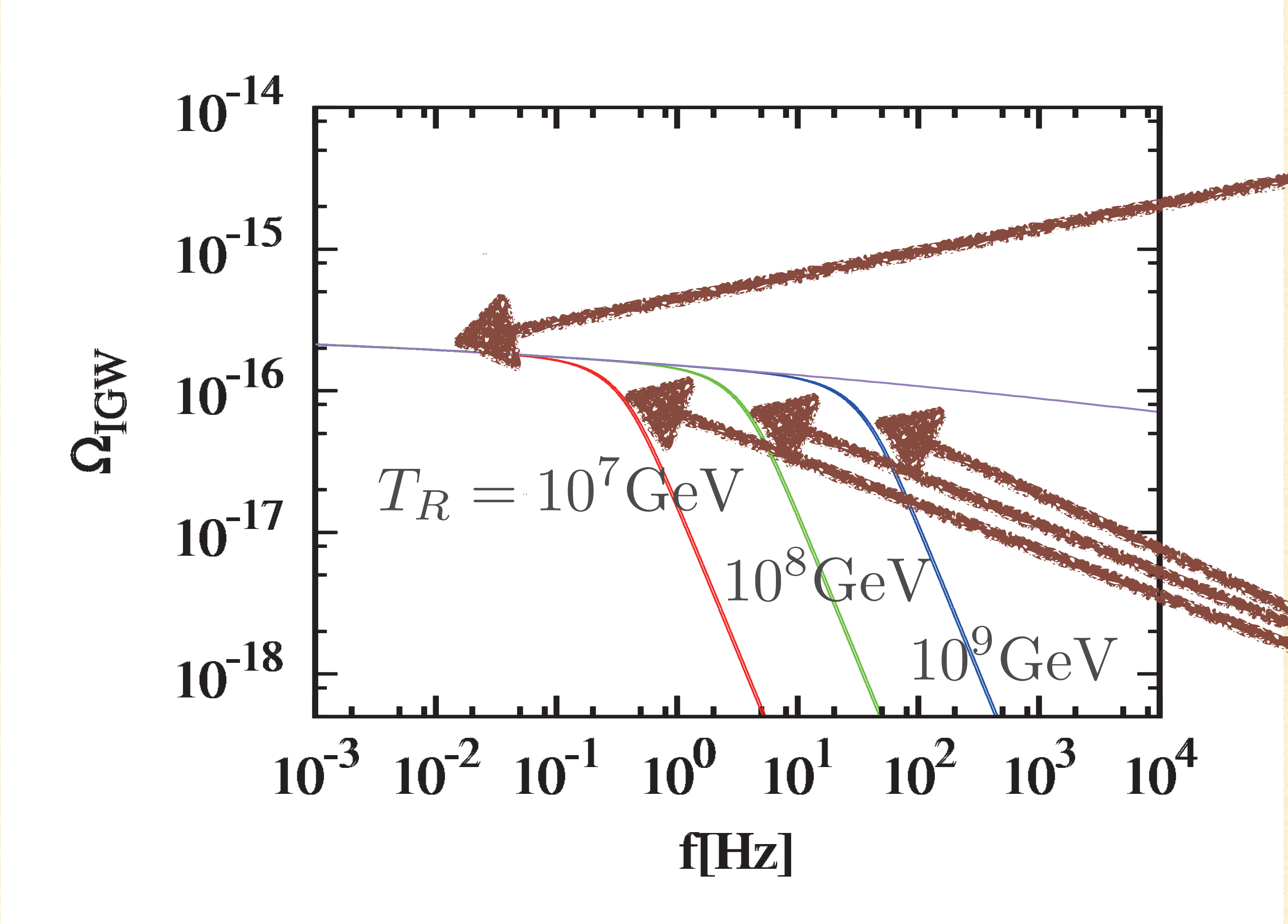
$$\begin{cases} n_T = -2\epsilon \\ \alpha_T = -4\epsilon(2\epsilon - \eta) \end{cases}$$

$$\left(\langle h_{ij}(x)^2 \rangle = \int d\ln k \, \mathcal{P}_{T,\mathrm{prim}}(k)\right)$$

PROPERTIES OF IGWS

- Numerically-calculated spectrum



Dependence on potential height & slow-roll

$\propto (k/k_*)^{n_T + \alpha_T \ln(k/k_*)/2}$

Effect of reheating

$$f_R = 2\pi k_R \simeq 0.3\text{Hz}\frac{T_R}{10^8\text{GeV}}$$

RESULT

- Sensitivities to $\Omega_{\rm GW}(f_*),\ n_T(f_*),\ \alpha_T(f_*)$

$n_T \& \alpha_T$ can be determined with $O(10^{-2})$ error

	BBO-std	BBO-grand
$\ln \bar{\Omega}_{\rm IGW}$(w/ $n_{\rm T}, \alpha_{\rm T}$)	3.1×10^{-2}	3.1×10^{-3}
$n_{\rm T}$ (w/ $\ln \bar{\Omega}_{\rm IGW}, \alpha_{\rm T}$)	9.6×10^{-2}	1.2×10^{-2}
$\alpha_{\rm T}$ (w/ $\ln \bar{\Omega}_{\rm IGW}, n_{\rm T}$)	0.28	3.5×10^{-2}

$(1\sigma,\ T_{\rm obs} = 10{\rm yrs})$

Fiducial values : predictions of ϕ^2 chaotic inflation

$$\begin{cases} r \simeq 0.15 \text{ (at CMB scale)} \\ n_T = -6.4 \times 10^{-2} \\ \alpha_T = -4.1 \times 10^{-3} \end{cases}$$

TALK PLAN

1. Introduction

2. Properties of inflationary GWs

3. χ^2 analysis

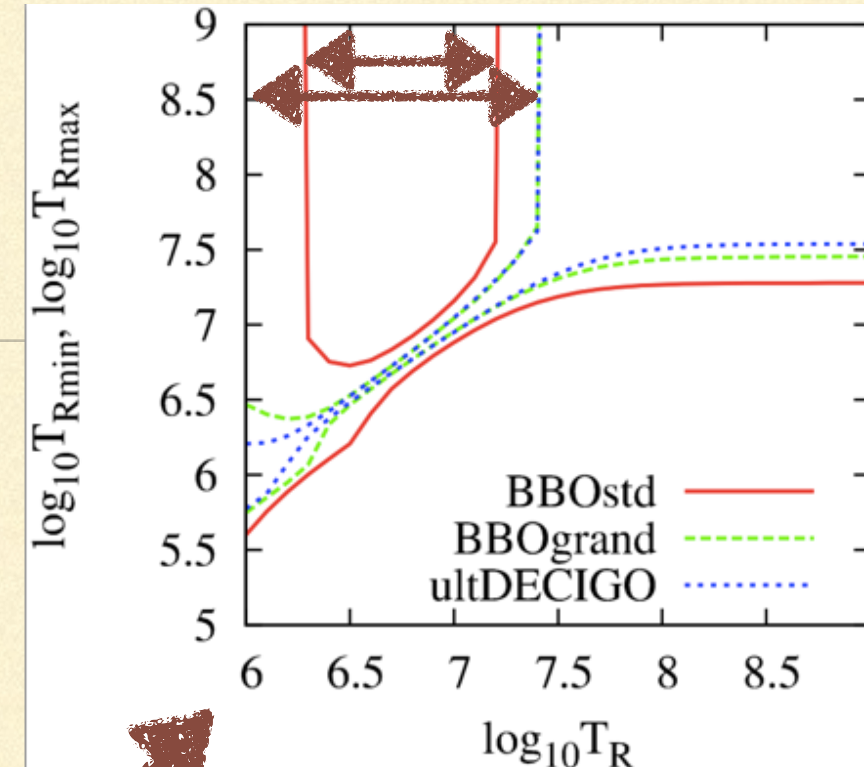
4. Result

5. Summary

SUMMARY

- If tensor-to-scalar ratio is sizable ($r \sim 0.1$),

  IGWs may be observed by space interferometers



- When T_R is relatively $\left\{ \begin{array}{c} \text{low} \\ \text{high} \end{array} \right\}$, determination of $\left\{ \begin{array}{c} T_R \\ \text{SRPs} \end{array} \right\}$ is expected

	BBO-std	BBO-grand
$\ln \bar{\Omega}_{\rm IGW} (\text{w/ } n_{\rm T}, \alpha_{\rm T})$	3.1×10^{-2}	3.1×10^{-3}
$n_{\rm T}$ $(\text{w/ } \ln \bar{\Omega}_{\rm IGW}, \alpha_{\rm T})$	9.6×10^{-2}	1.2×10^{-2}
$\alpha_{\rm T}$ $(\text{w/ } \ln \bar{\Omega}_{\rm IGW}, n_{\rm T})$	0.28	3.5×10^{-2}

- If r is sizable, space interferometers are strongly suggested