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Effects of Inflationary Particle Production on Local Temperature Fluctuations in the CMB

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In Collaboration with:

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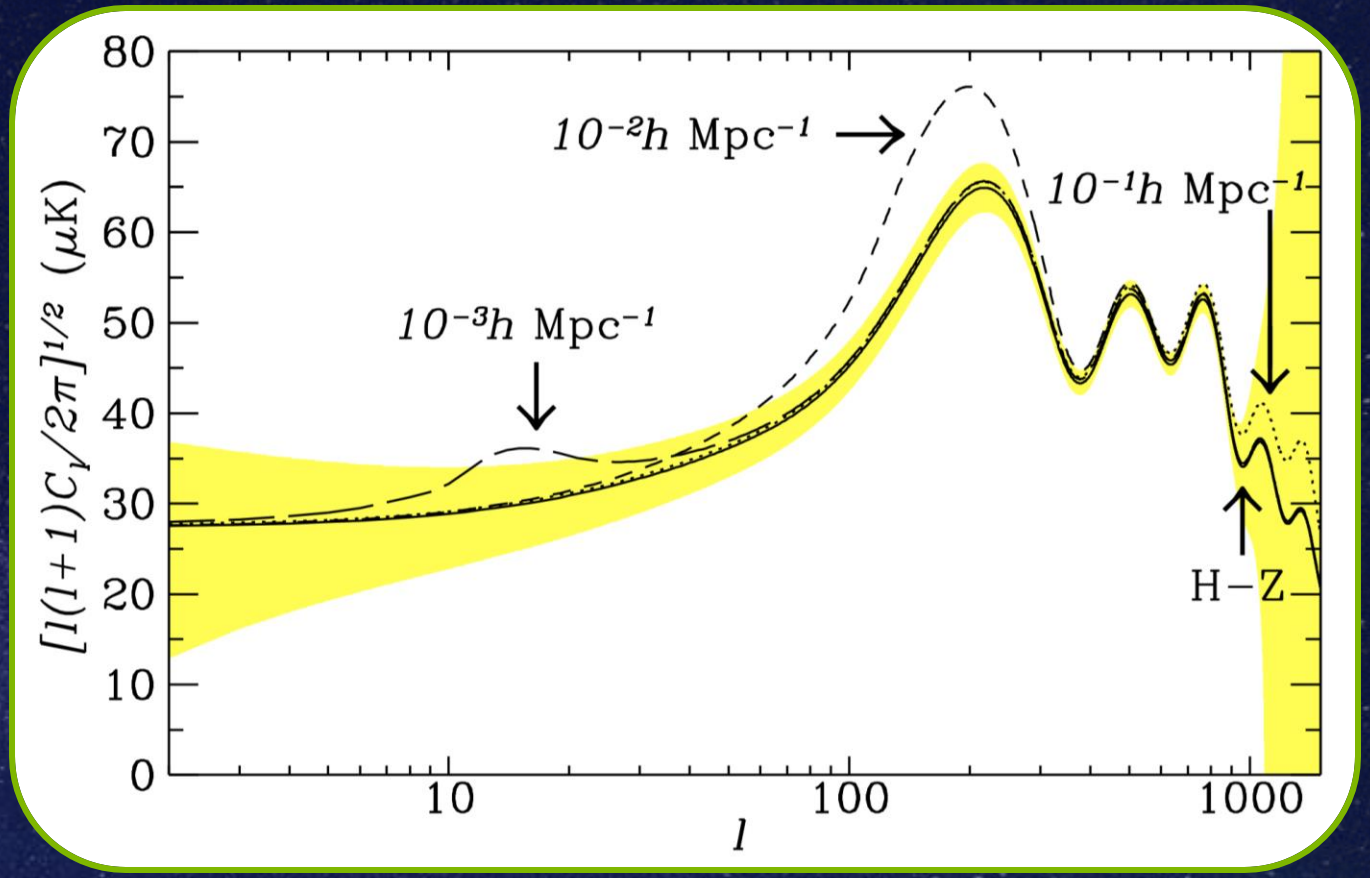
History

- 1999 Chung et al. [ArXiv: 9910437]:
  - →Massive particle production during inflation.
  - →Model dependent signal on the primordial power spectrum

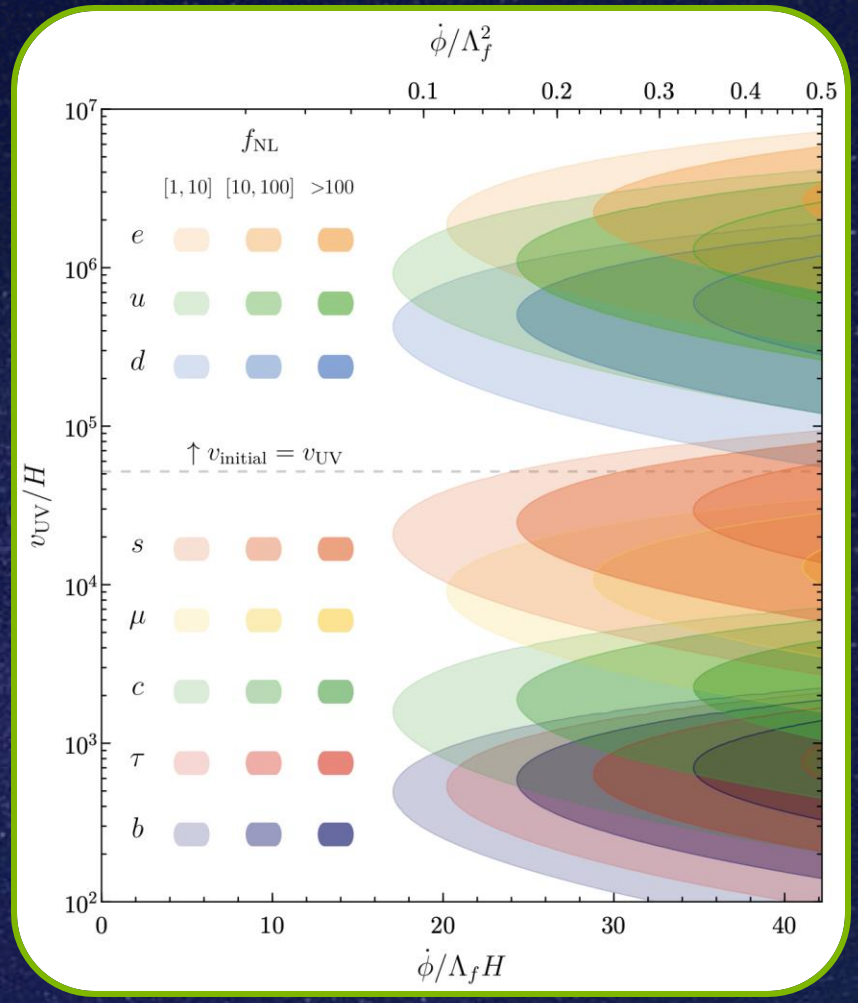


Simulation of Angular Power Spectrum with massive particle Production during inflation

Taken from: Chung et al. [ArXiv: 9910437]

Cosmological Collider Physics

- 2019 Arkani-Hamed and Maldacena [ArXiv: 503.08043]:
  - High energies during Inflation.
  - How can we ‘detect’ particles that were produced during that time?
    - →2018 Chen et al. [ArXiv:1805.02656]: Neutrino production
    - →2019 Hook et al. [ArXiv: 1907.10624]: Fermion production
    - →2020 Wang et al. [ArXiv:2004.02887]: Gauge Boson production



Size of Non-Gaussianity from SM fermion production.

Taken from: Hook et al. [ArXiv: 1907.10624]

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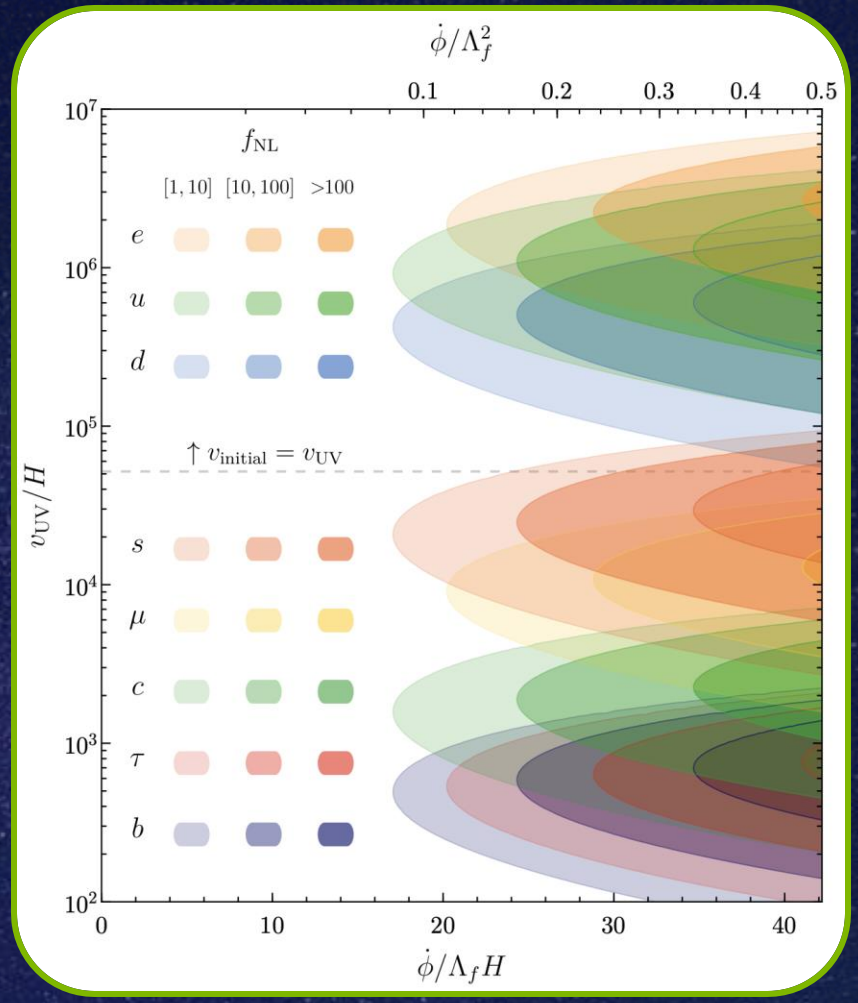
→Up until now only momentum Space



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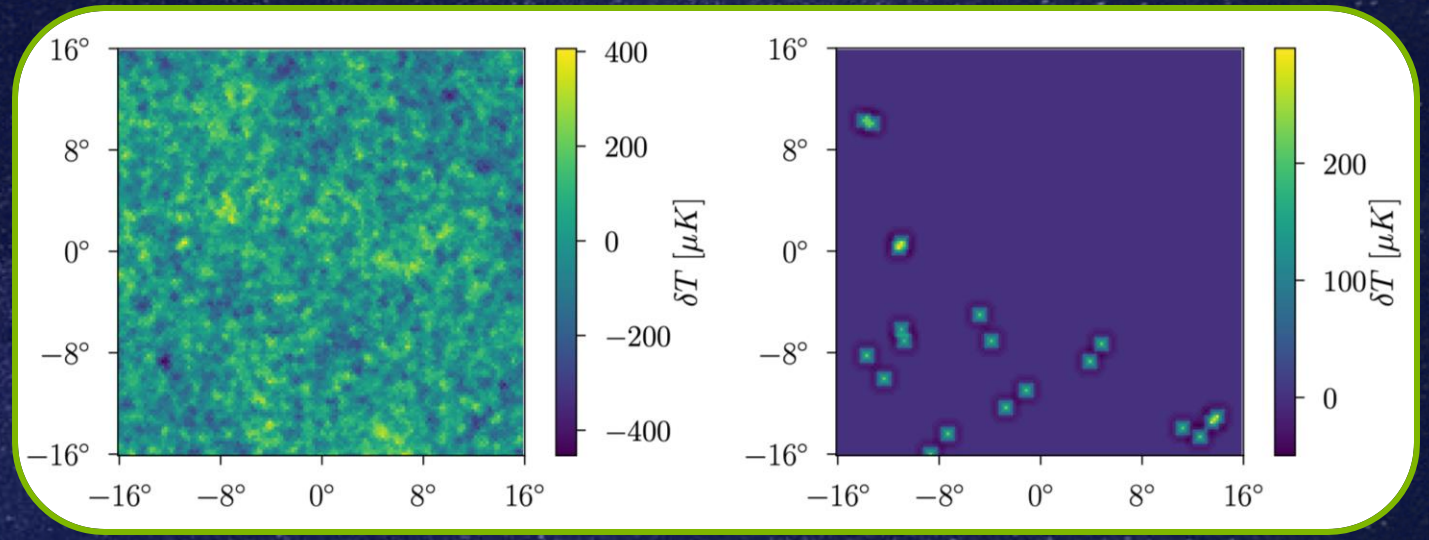
Searches in Physical Space – 2021 Kim, Kumar, Martin, Tsai [ArXiv:2017.09061]

- Heavy scalar particles coupling to inflaton can produce pairwise hot/cold spot signatures in CMB
- These events are rarer
- Hot/cold spot signatures detectable at lowest order ~ 1 microkelvin



Simulated Local CMB + PHS (left) and PHS (right) maps using HEALPix.

Taken from: Kim et al. [ArXiv: 2107.09061]

The Tachyonic Higgs

tachyonic instability:

particle numbers and sizes of inhomogeneities increase exponentially

→ Stronger Signal since more particles.

→ This is already part of the SM.

The Tachyonic Higgs

$$V = -\frac{m^2}{2}h^2 + \frac{\lambda}{4}h^4$$

At 10^{11} GeV; SM Higgs quartic coupling becomes negative

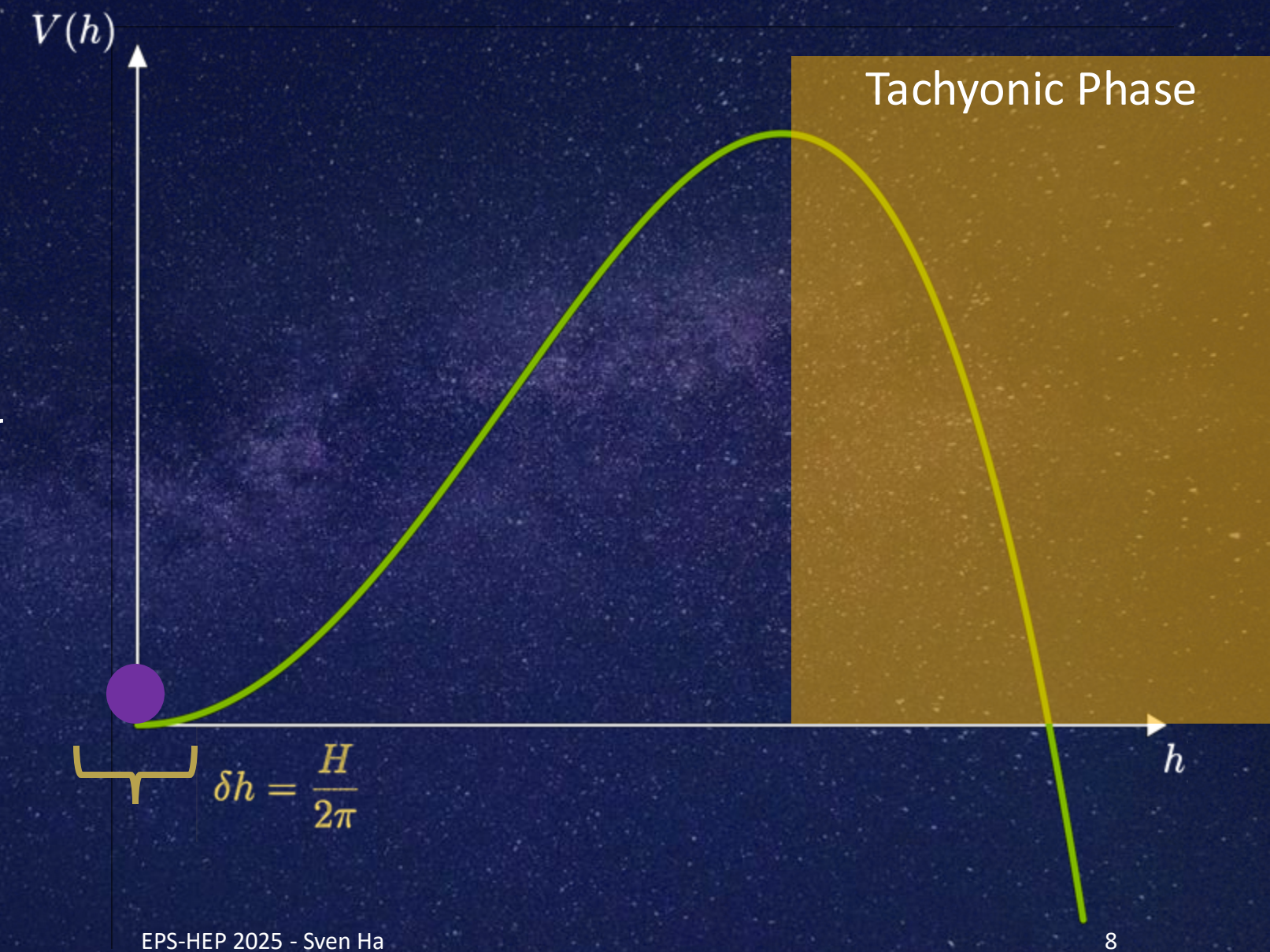
$$m_h^2(h) = V_{hh} = 3\lambda h^2$$

Higgs mass squared is negative.
Higgs becomes tachyonic

The Tachyonic Higgs

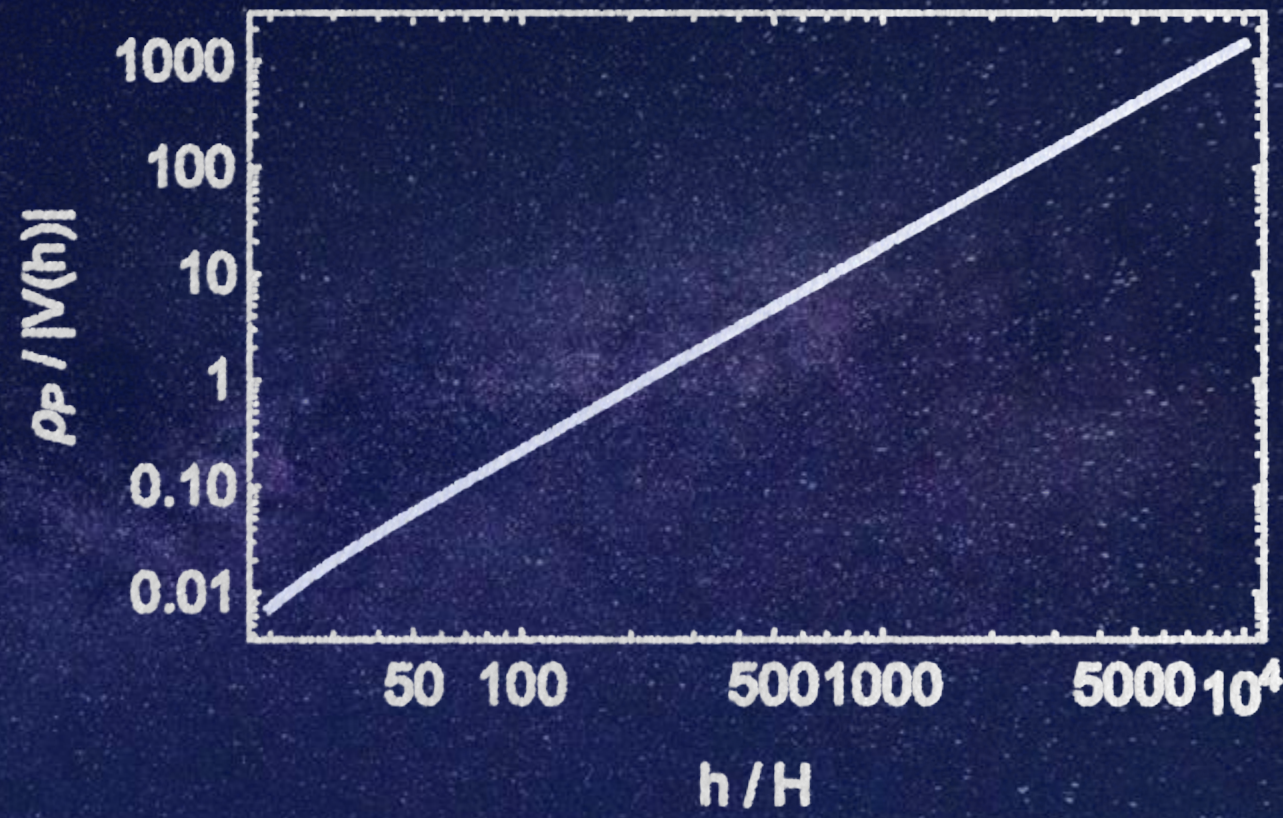
Cosmic inflation causes perturbations of any scalar particle.

→ Higgs can undergo tachyonic phase transition



The Tachyonic Higgs

- Tachyonic mass of the Higgs produces Higgs particles out of vacuum
- Very large inhomogeneities in a few local patches of the Universe



Ratio of energy density in Higgs particles to the potential energy of the Higgs field.

Taken from: Shakya et al. [ArXiv: 2301.08754]

Our Goal:
hot/cold spot signatures
as observable signals in the CMB
from tachyonic Higgs

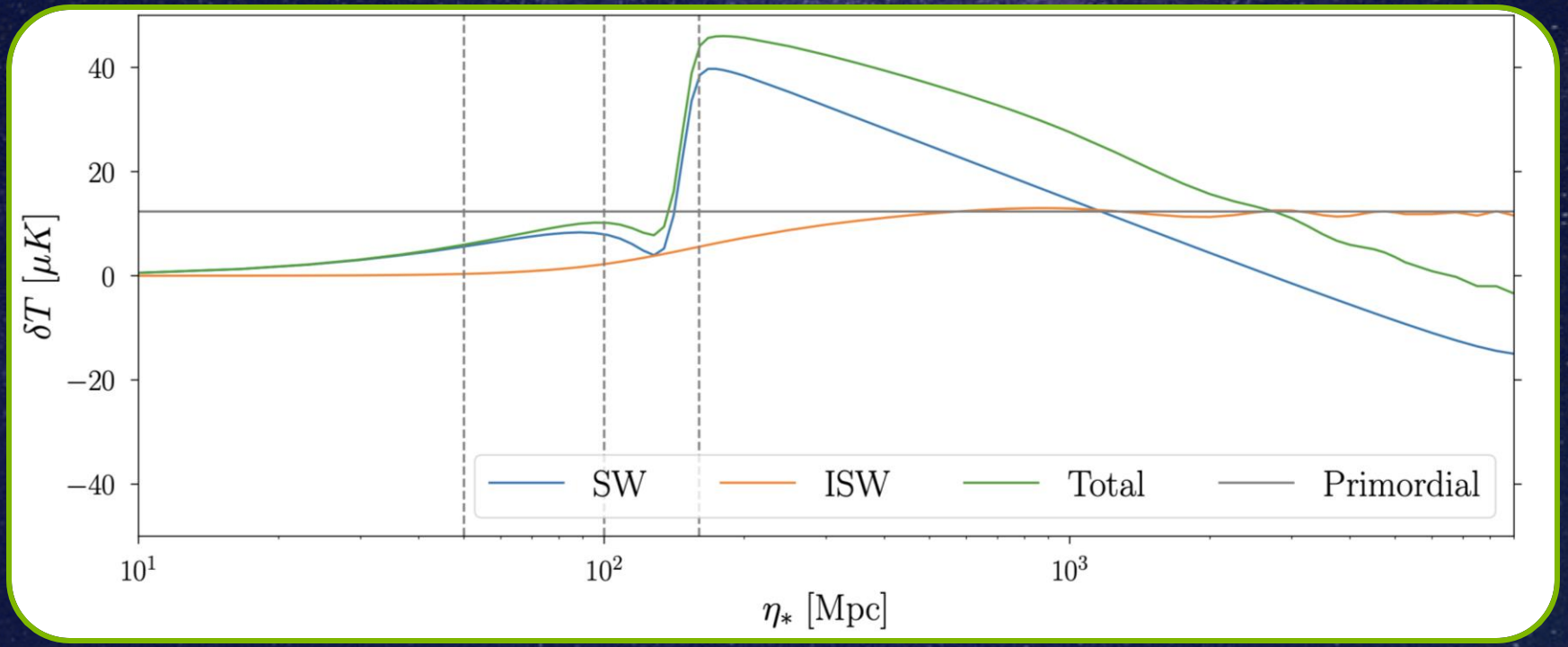
Previous Work – 2021 Kim, Kumar, Martin, Tsai [ArXiv: 2107.09061]

Using CLASS (Cosmic Linear Anisotropy Solving System)

by Lesgourges et al. [ArXiv: 1104.2933]:

Temperature of the center of the hot/cold spot as a function of horizon size.

Taken from:
Kim et al. [ArXiv: 2107.09061]



What do we need to evaluate?

Sachs-Wolfe and integrated Sachs-Wolfe

$$\theta(\vec{x}_0,\hat{n},\eta_0) = \frac{4\pi}{(2\pi)^3}\int_0^\infty \frac{dk}{k}\sum_l j_l(k\eta_0 - k\eta_{\rm rec})(2l+1)\mathcal{P}_l(\hat{n}\cdot\hat{n}_{\rm HS})\left(f_{\rm SW}(k)+f_{\rm ISW}(k)\right) f(k\eta_*)$$

Legendre and Spherical Bessel Polynomial

Mass function

$$\theta_l(k,\eta_0) \approx \left(\theta_0(k,\eta_{\rm rec})+\Psi(k,\eta_{\rm rec})\right) j_l(k(\eta_0-\eta_{\rm rec})) + \int_0^{\eta_0} d\eta e^{-\tau}\left(\Psi'(k,\eta)-\Phi'(k,\eta)\right) j_l(k(\eta_0-\eta))$$

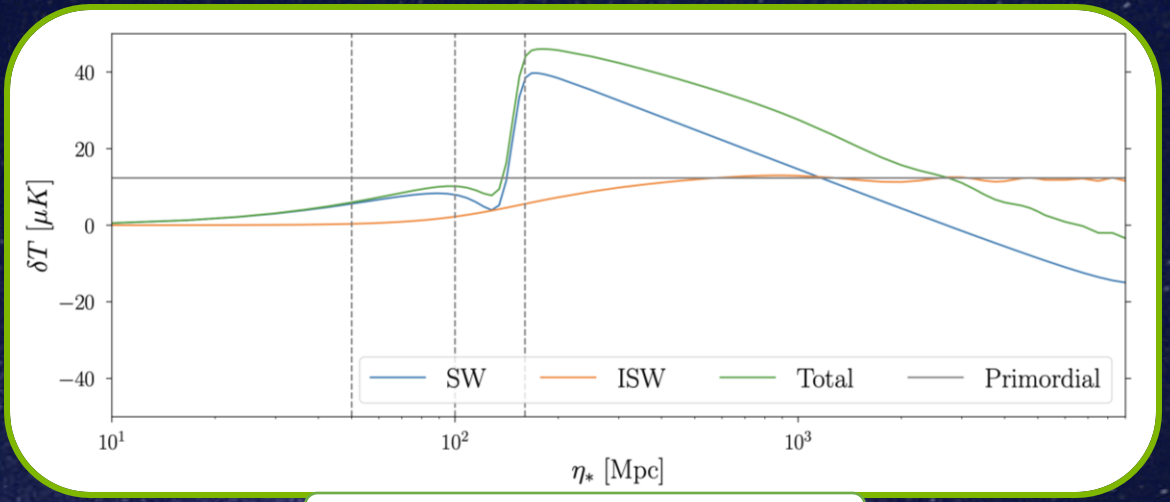
Sachs-Wolfe

Integrated Sachs-Wolfe

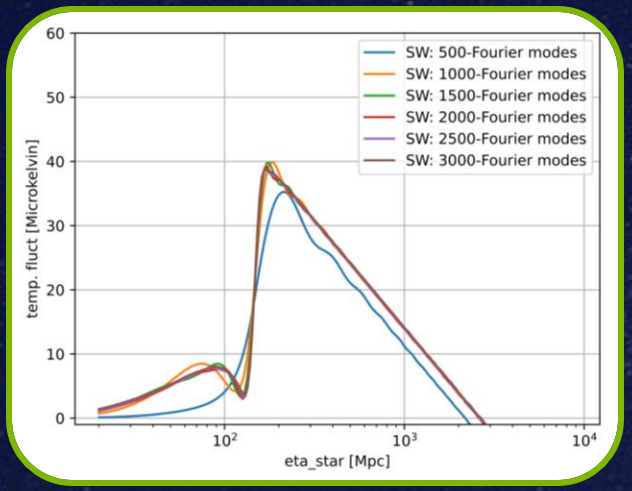
→ Redshift is negligible due to the symmetric profile of temperature fluctuations

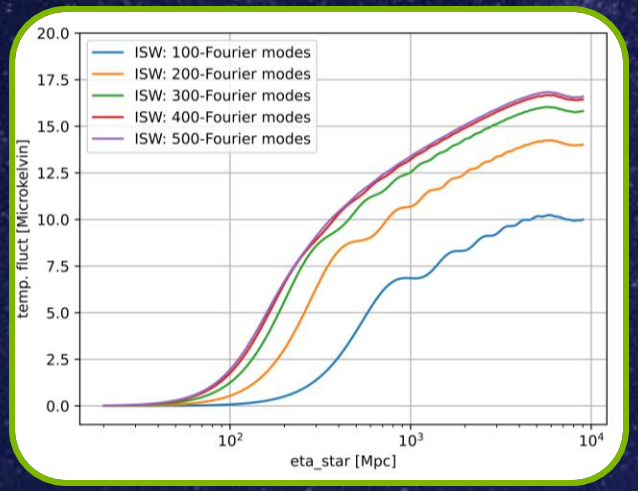
Progress so far

- Implemented work of Kim et al. with multiprocessing

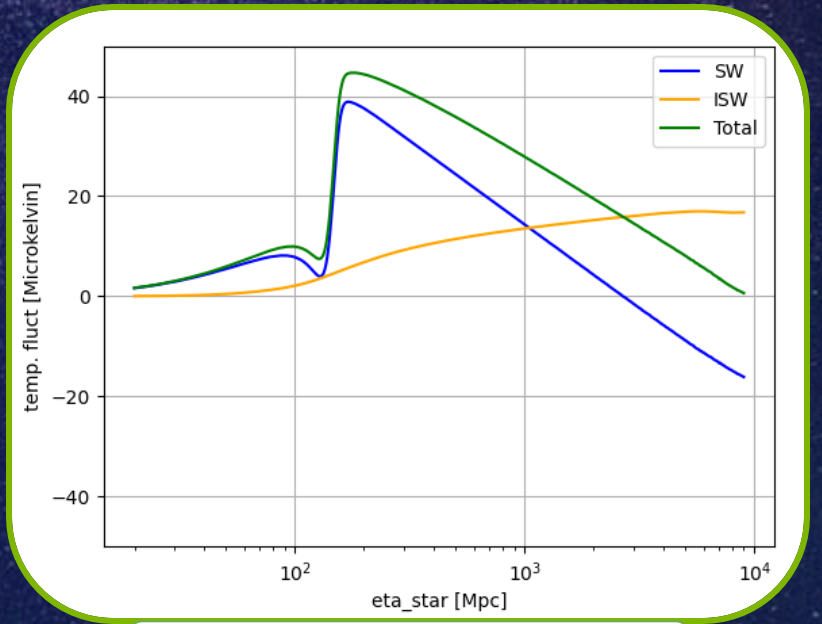


Kim et. al.





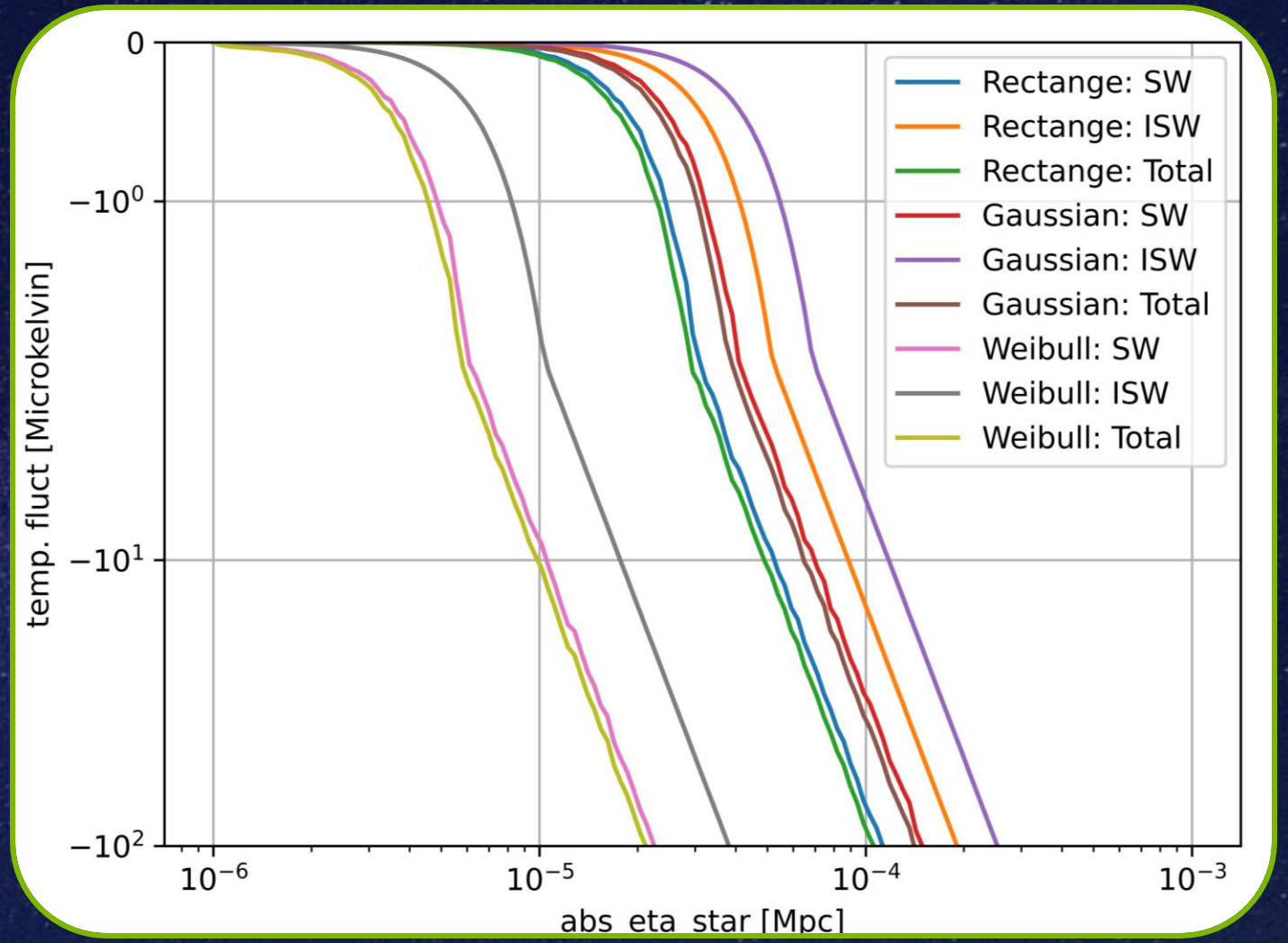
Analysis of Fourier components.



Our Plot

Progress so far

- Implemented work of Kim et al. with multiprocessing
- Implemented simplified mass functions
  - Weibull-like distribution gives the largest temperature signature
  - Includes black hole mass functions
  - More massive particles
    - ↳ Bigger temp. fluctuation



Next Step:

Implement the parameters of the SM Higgs into our code.

Analysis of how Higgs fluctuations grow.

Summary

- Particle Production during Inflation can leave observable relics; indirect and direct.
- Heavy particle production can leave local hot/cold spots in the CMB.
- Tachyonic Higgs as mechanism during inflation can exponentially amplify minor perturbations in the early Universe.
- We have rebuilt the framework by Kim et al. to look at the tachyonic Higgs.

Any Questions?

Thank you.