Missing Scalars at the Cosmological Collider

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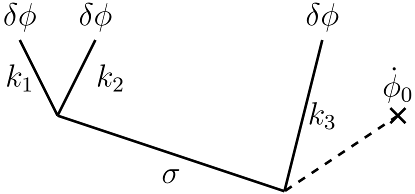
Cosmological Collider?

dynamics during inflation produces density perturbations that we see at CMB, large scale structure, 21cm etc.

The energy scale of the "high energy collision" is set by Hubble during inflation, H

“Bump hunt” for cosmological collider

Three-point correlation function mediated by scalar σ from $\sigma(\partial_\mu\phi)^2$ interaction



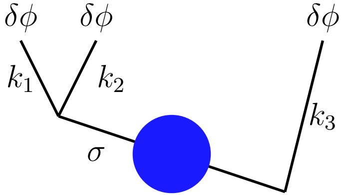
$$S(k_1 = k_2 \gg k_3) = A(\lambda, m)\left(\frac{k_3}{k_1}\right)^{\frac{1}{2}\pm\nu_\sigma}$$

$$\nu_\sigma = \sqrt{\frac{9}{4} - \frac{m_\sigma^2}{H^2}}$$

Chen, Wang, 0911.3380;1205.0160 Pi, Sasaki, 1205.0161

Arkani-Hamed, Maldacena, 1503.08043

Missing scalars

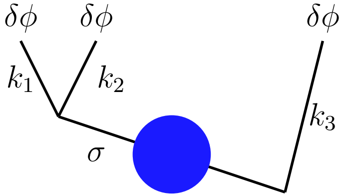


interaction with χ

$$S(k_1 = k_2 \gg k_3) =?$$

Missing scalars

Two fields, σ and χ, where $m_\sigma^2 > 9/4H^2$, and $m_\chi^2 < H^2$
with interaction $\frac{g}{2}\sigma^2\chi^2$



interaction with χ

$$S(k_1 = k_2 \gg k_3) = ?$$

The Rest of the Talk

Our signal: infer existence of χ through the space-dependent mass correction it gives to σ — a de Sitter “thermal” effect

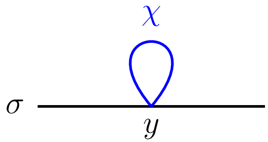
- Physical intuition behind the signal
- Results from calculation in Euclidean de Sitter space

What is the effect of χ-σ interaction?

A light field in de Sitter has $\mathcal{O}(H)$ fluctuation in space due to the "thermal" kick from the background with "temperature" H

Constant mass correction at leading order

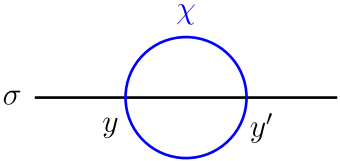
A light field in de Sitter has $\mathcal{O}(H)$ fluctuation in space due to the "thermal" kick from the background with "temperature" H



Integrate the single interaction point y over space, no space-dependence effect, constant mass correction

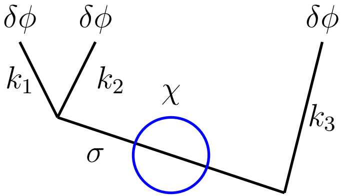
Space-dependent de Sitter "thermal" mass correction

A light field in de Sitter has $\mathcal{O}(H)$ fluctuation in space due to the "thermal" kick from the background with "temperature" H



When y and y' have large distance, see variation in χ values
Different correction to m_σ at different point in space
σ at different point in space are less correlated

Space-dependent de Sitter "thermal" mass correction



$$S_{\text{dS thermal}}(k_1 = k_2 \gg k_3) = A(\lambda, m)\left(\frac{k_3}{k_1}\right)^{\frac{1}{2}\pm \mathrm{i}\nu_\sigma + \alpha}$$

$$\nu_\sigma = \sqrt{\frac{m_\sigma^2}{H^2} - \frac{9}{4}},\ \alpha > 0$$

Going to Euclidean de Sitter

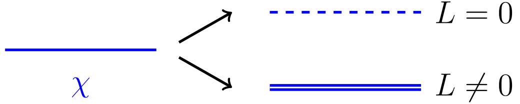
- Euclidean de Sitter space is a 4-dimensional sphere
- Momentum in euclidean de Sitter space is quantized (like spherical harmonics)
- A free field propagator can be written as a sum over the discrete dimensionless momentum

$$\langle f(x_1)f(x_2)\rangle = \sum_{\vec{L}} \frac{Y_{\vec{L}}(x_1)Y^*_{\vec{L}}(x_2)}{m_f^2/H^2 + L(L+3)}$$

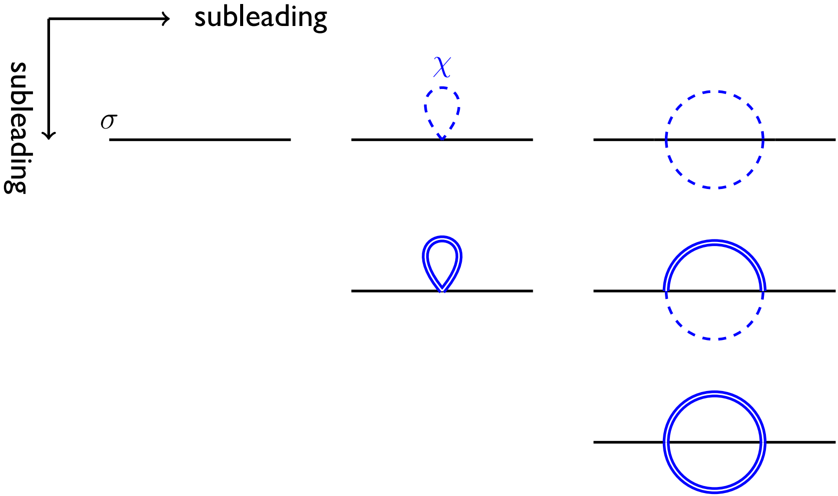
Zero mode propagators are enhanced

$$\langle f(x_1) f(x_2) \rangle = \sum_{\vec{L}} \frac{Y_{\vec{L}}(x_1) Y^*_{\vec{L}}(x_2)}{m_f^2/H^2 + L(L+3)}$$

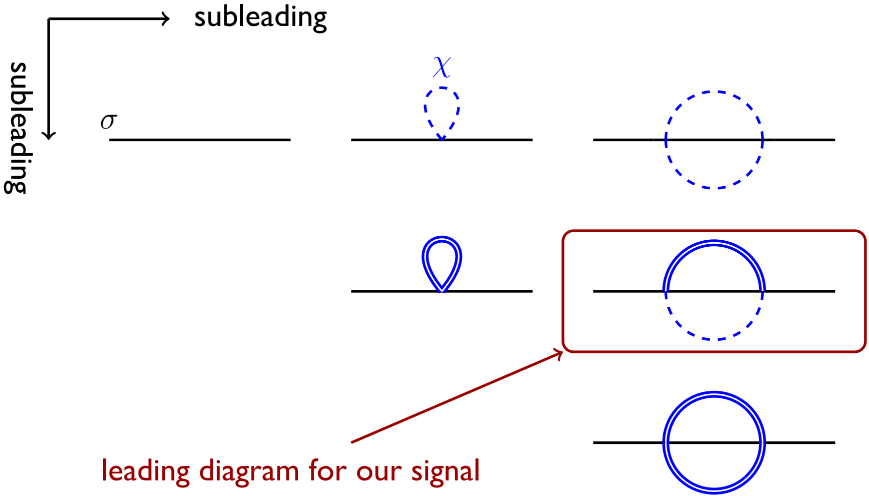
When $m_f^2 < H^2$, $\quad \dfrac{1}{m_f^2/H^2} > \dfrac{1}{m_f^2/H^2 + L(L+3)}$



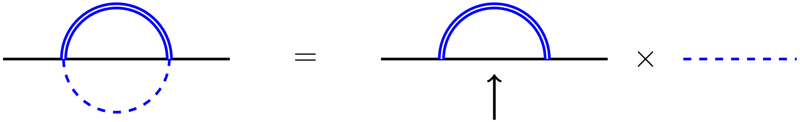
Double expansion of Feynman diagrams



Double expansion of Feynman diagrams



Result: qualitative feature



Calculated by Marolf & Morrison 1006.0035

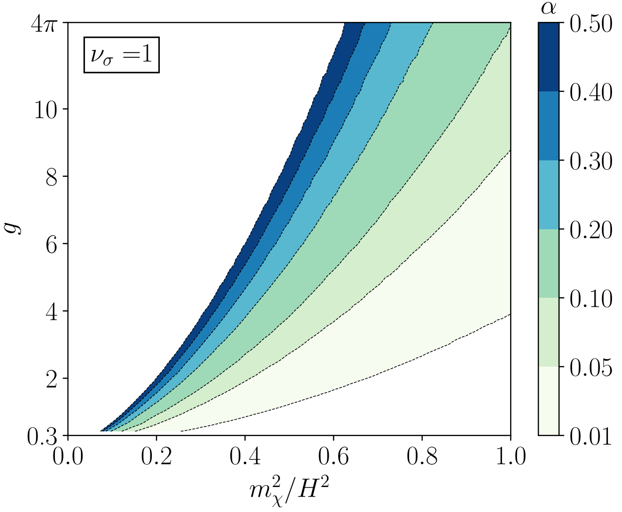
$$S_{\text{dS thermal}} = A(\lambda, m)\left(\frac{k_3}{k_1}\right)^{\frac{1}{2}\pm \mathrm{i}\nu_\sigma + \alpha}$$

$$\nu_\sigma = \sqrt{\frac{m_\sigma^2}{H^2} - \frac{9}{4}}$$

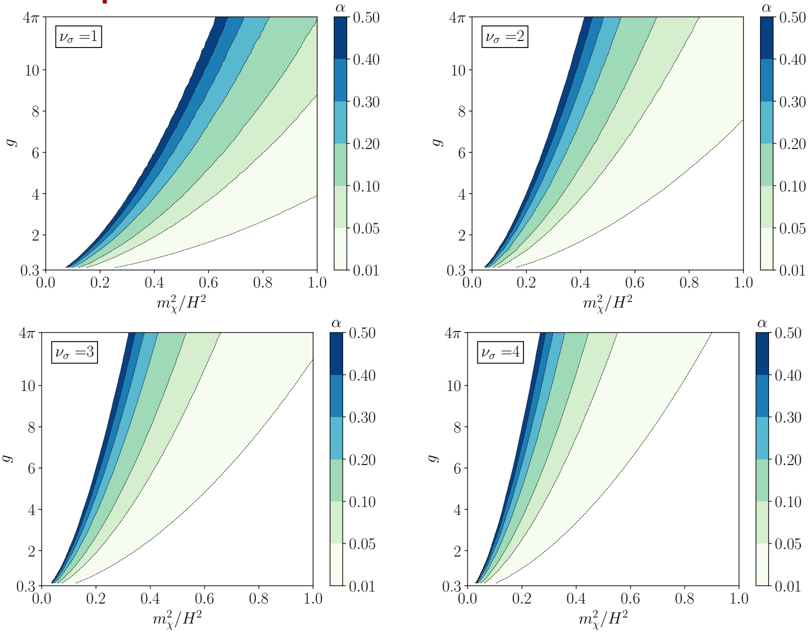
Result: quantitative feature

$$V(\sigma,\chi) = \frac{1}{2}m_\sigma^2\sigma^2 + \frac{1}{2}m_\chi^2\chi^2 + \frac{g}{2}\sigma^2\chi^2$$

$$S_{\text{dS thermal}}(k_1 = k_2 \gg k_3) = A(\lambda, m)\left(\frac{k_3}{k_1}\right)^{\frac{1}{2}\pm i\nu_\sigma + \alpha}$$



Result: quantitative feature



Conclusion

- Light fields without direct coupling with inflaton can be detected through interaction with other scalars
- They imprint a unique de Sitter "thermal" mass correction on a massive field σ that couples to the inflaton, causing inflaton bispectrum to be less correlated at large squeezedness
- In Euclidean de Sitter space, the zero mode of the light field is enhanced compared to nonzero mode, which help simplify calculations
- The de Sitter "thermal" mass correction is potentially observable at large-scale structure and 21cm experiments for $\mathcal{O}(1)$ $\chi - \sigma$ coupling and $m_\chi^2 \lesssim H^2$

Backup Slides

Observational prospect

$$S_{\text{dS thermal}} = A(\lambda, m)\left(\frac{k_3}{k_1}\right)^{\frac{1}{2}\pm i\nu_\sigma+\alpha}$$

$S_{\text{dS thermal}}$ has the same dependence on ν_ϕ and α, up to a phase shift

Meerburg, Münchmeyer, Munõz, Chen 1610.06559
Fisher forecast for 21cm surveys:
$\Delta v_\sigma \approx 0.01$ for $f_{\text{NL}} = 1 \Rightarrow \alpha_{\text{min}} \approx 0.01$

Observational prospect

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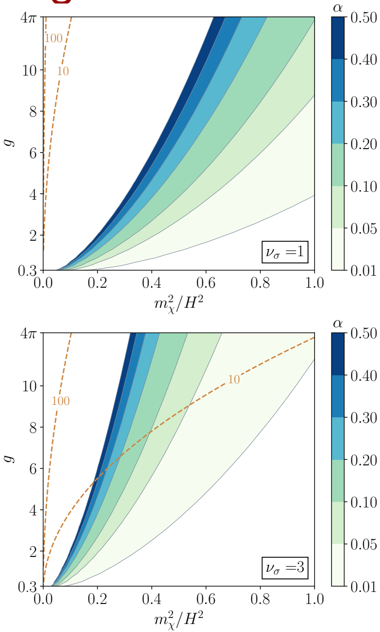
$\alpha_{\text{max}} = 1/2$ for this Fisher forecast

Tuning



α
0.50
0.40
0.30
0.20
0.10
0.05
0.01
4π
10
8
6
4
2
0.3
0.0
0.2
0.4
0.6
0.8
1.0
g
m_χ^2/H^2
100
10
$\nu_\sigma = 1$
$\nu_\sigma = 2$
$\nu_\sigma = 3$
$\nu_\sigma = 4$

σ-χ vs σ self-interaction

- σ self-interaction (e.g. σ^3) also generates similar loss of correlation effect
  Arkani-Hamed & Maldacena '15, Jatkar et al. '11
  Boyanovsky '12, Krotov & Polyakov '10
- But σ^3 is suppressed by the need to create heavy σ out of the vacuum, and the lack of zero-mode enhancement from a light field
- In the range of α we have plotted, α is unambiguously coming from $\sigma - \chi$ interaction.