Missing Scalars at the Cosmological Collider

Work in progress
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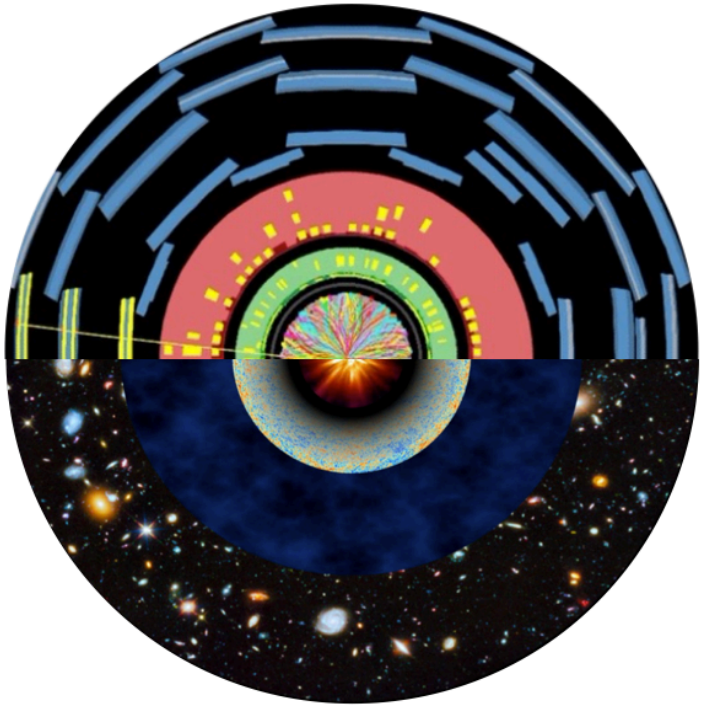
Cosmology from Home 2021, July 2021

Cosmological Collider?

high energy collision produces long-lived particles
that we see in detectors



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

Cosmological Collider?

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

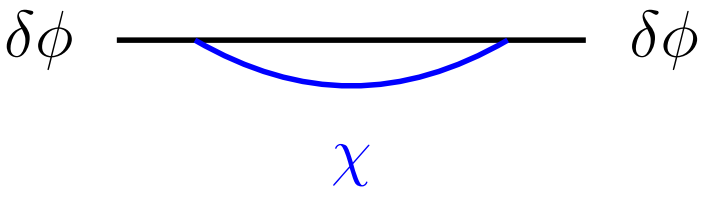
dynamics during inflation produces density perturbations
that we see at CMB, large scale structure, 21cm etc.

The Goal of This Talk

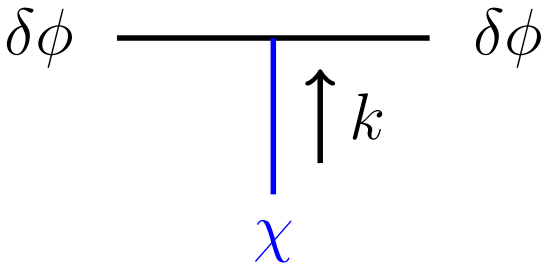
Observational signal of light scalars ($m^2 < H^2$)
in cosmological collider

- "missing": particles lighter than hubble are difficult to detect despite their copious production
- Our signal: infer existence of light scalars through the space-dependent mass correction they give to heavier scalars — a de Sitter "thermal" effect
- Results from calculation in Euclidean de Sitter space
- Preliminary Fisher forcast

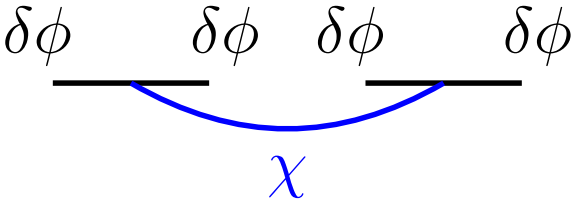
It's difficult to infer existence of new particles...



not distinguishable from
changes in inflaton potential



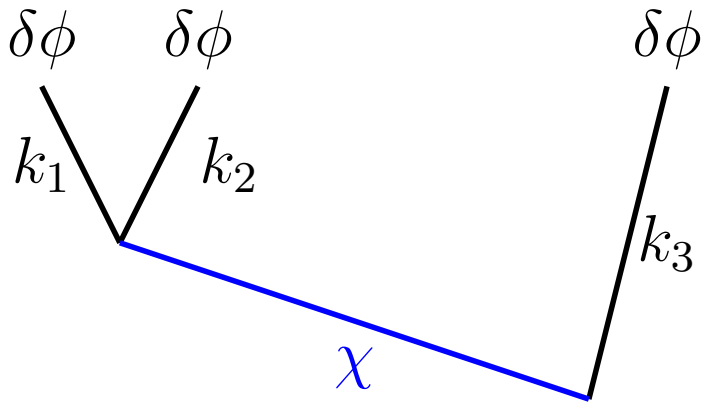
violates momentum conservation,
but not observable in ensemble average



four-point function of $\delta\phi$
difficult to measure

Dai, Jeong, Kamionkowski 1302.1868

...especially when they are light



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

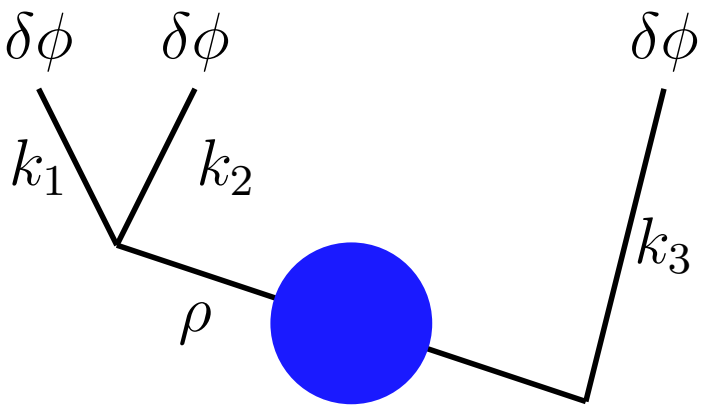
$$\nu_\chi = \sqrt{\frac{9}{4} - \frac{m_\chi^2}{H^2}}$$

Qualitatively different behavior when $m^2 < \frac{9}{4}H^2$ and $m^2 > \frac{9}{4}H^2$
for $m^2 < \frac{9}{4}H^2$, hard to dig out from large background

Chen, Wang, 0911.3380;1205.0160 Pi, Sasaki, 1205.0161
Arkani-Hamed, Maldacena, 1503.08043

Our signal: de Sitter "thermal" mass correction

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



interaction with χ

Space-dependence of 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

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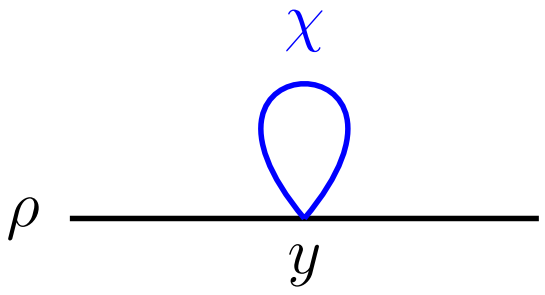

Integrate the single interaction point y over space,
no space-dependence effect, constant mass correction

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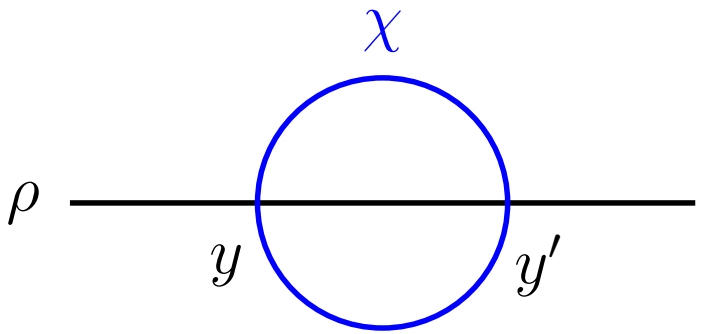


When y and y' have super-Hubble distance, see variation in χ values

Different correction to m_ρ at different point in space

ρ at different point in space are less correlated

Going to Euclidean de Sitter

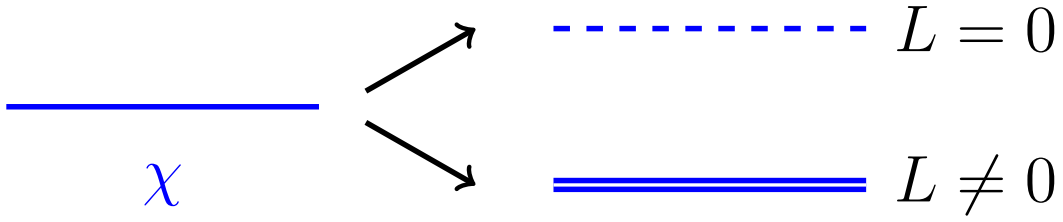
- Euclidean de Sitter space is a 4-dimensional sphere
- Momentum in euclidean de Sitter space is quantized (like spherical harmonics)
- A free field propagator can be written as a sum over the discrete dimensionless momentum

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

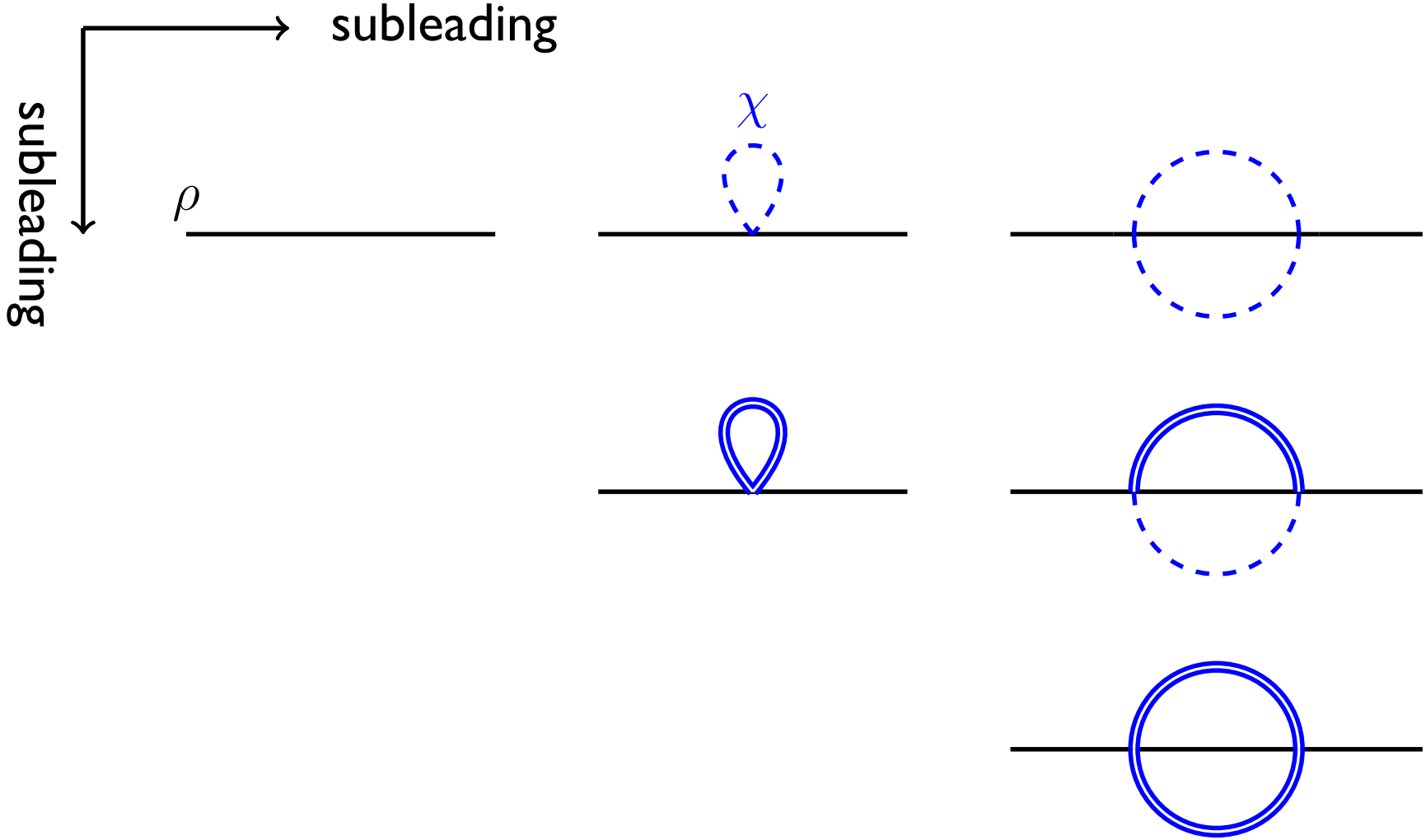
Zero mode propagators are enhanced

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

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



Double expansion of Feynman diagrams



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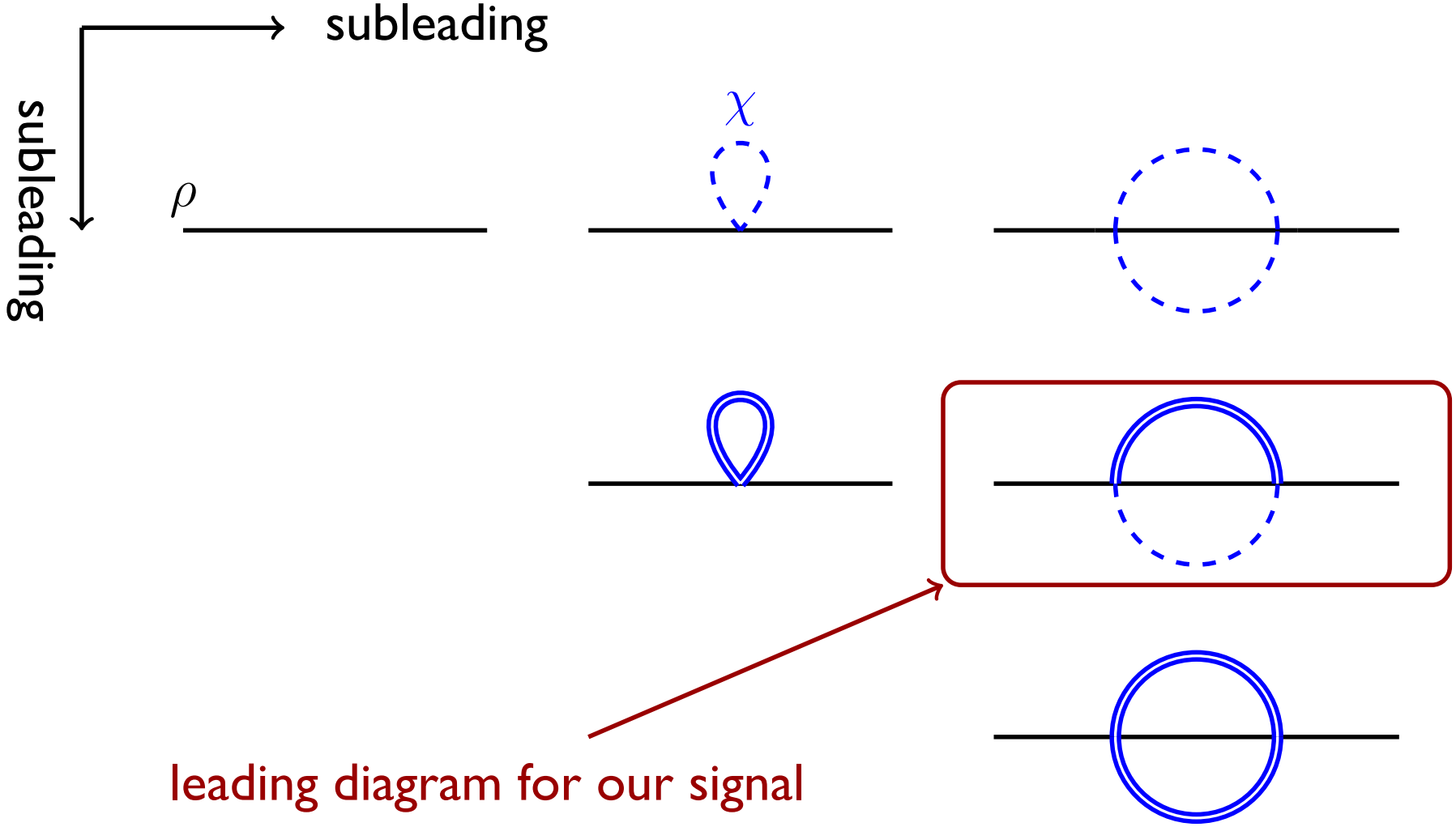
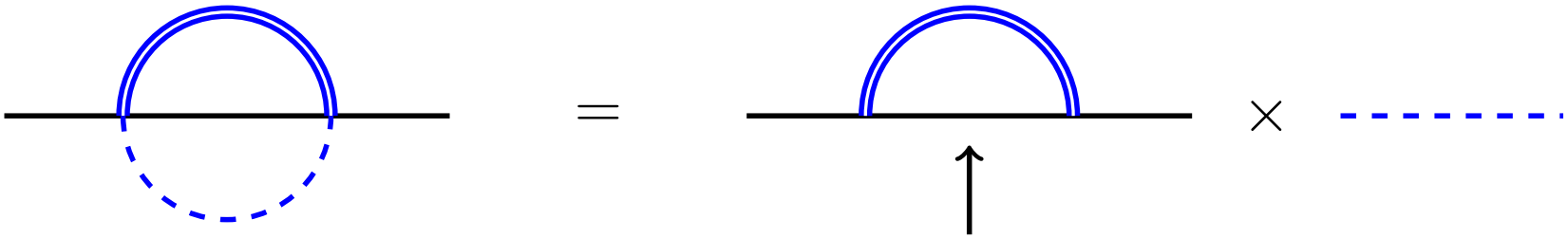


Result: qualitative feature



Calculated by Marolf & Morrison 1006.0035

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

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

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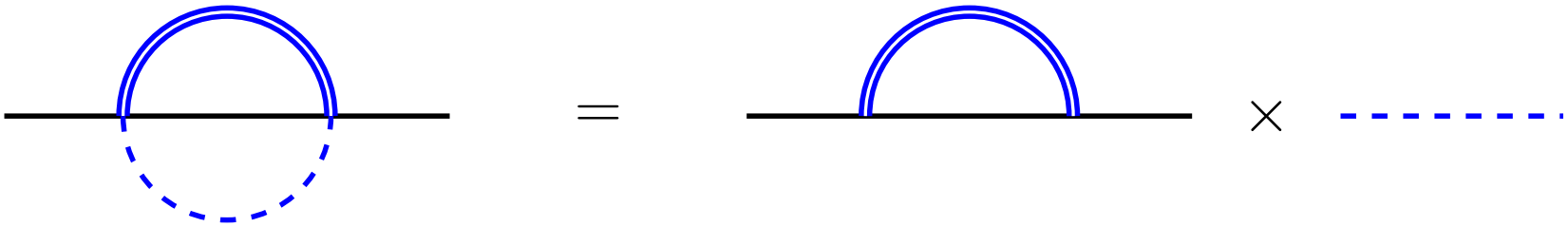

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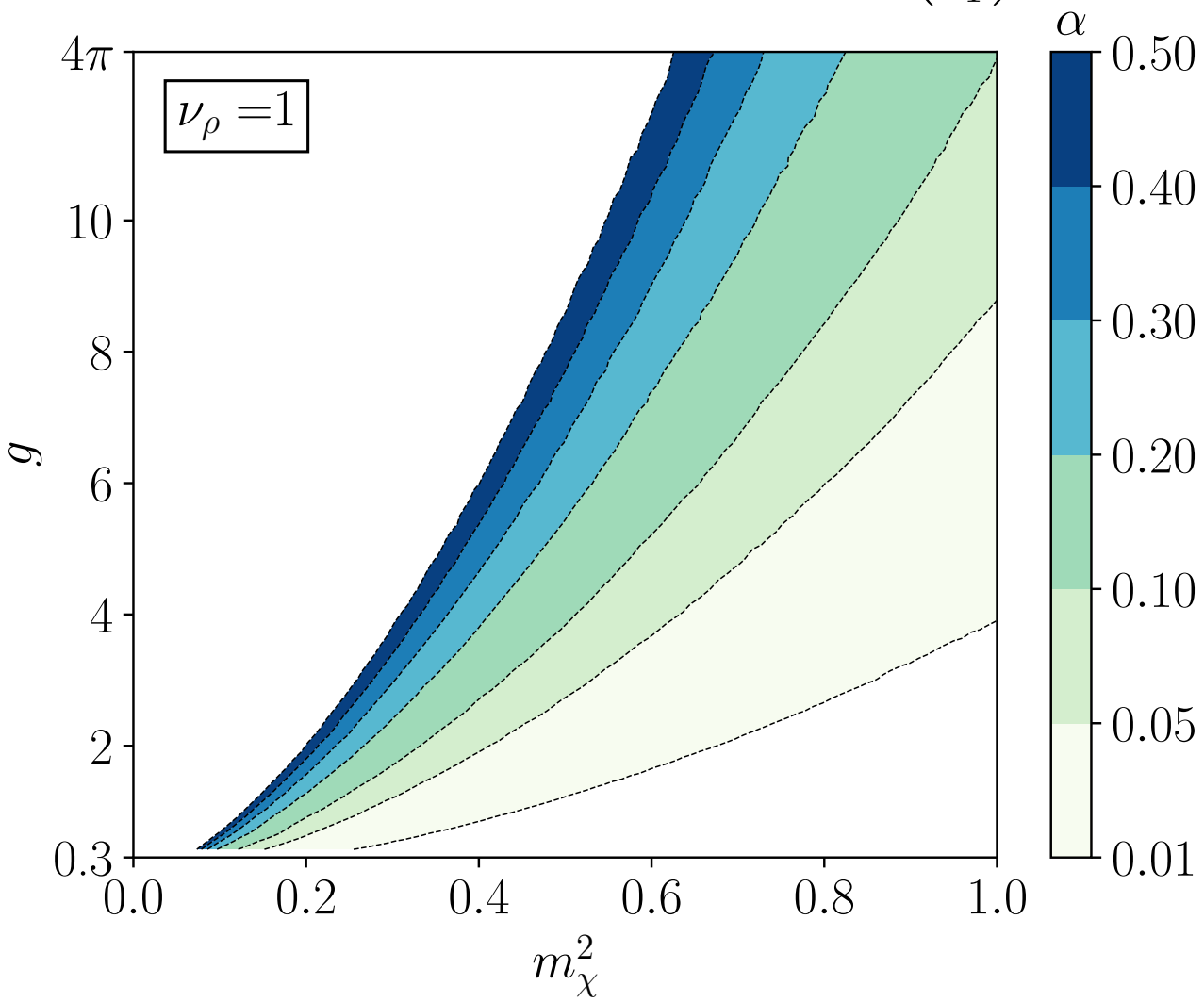
$$\nu_\rho = \sqrt{\frac{m_\rho^2}{H^2} - \frac{9}{4}}$$

Result: quantitative feature

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

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



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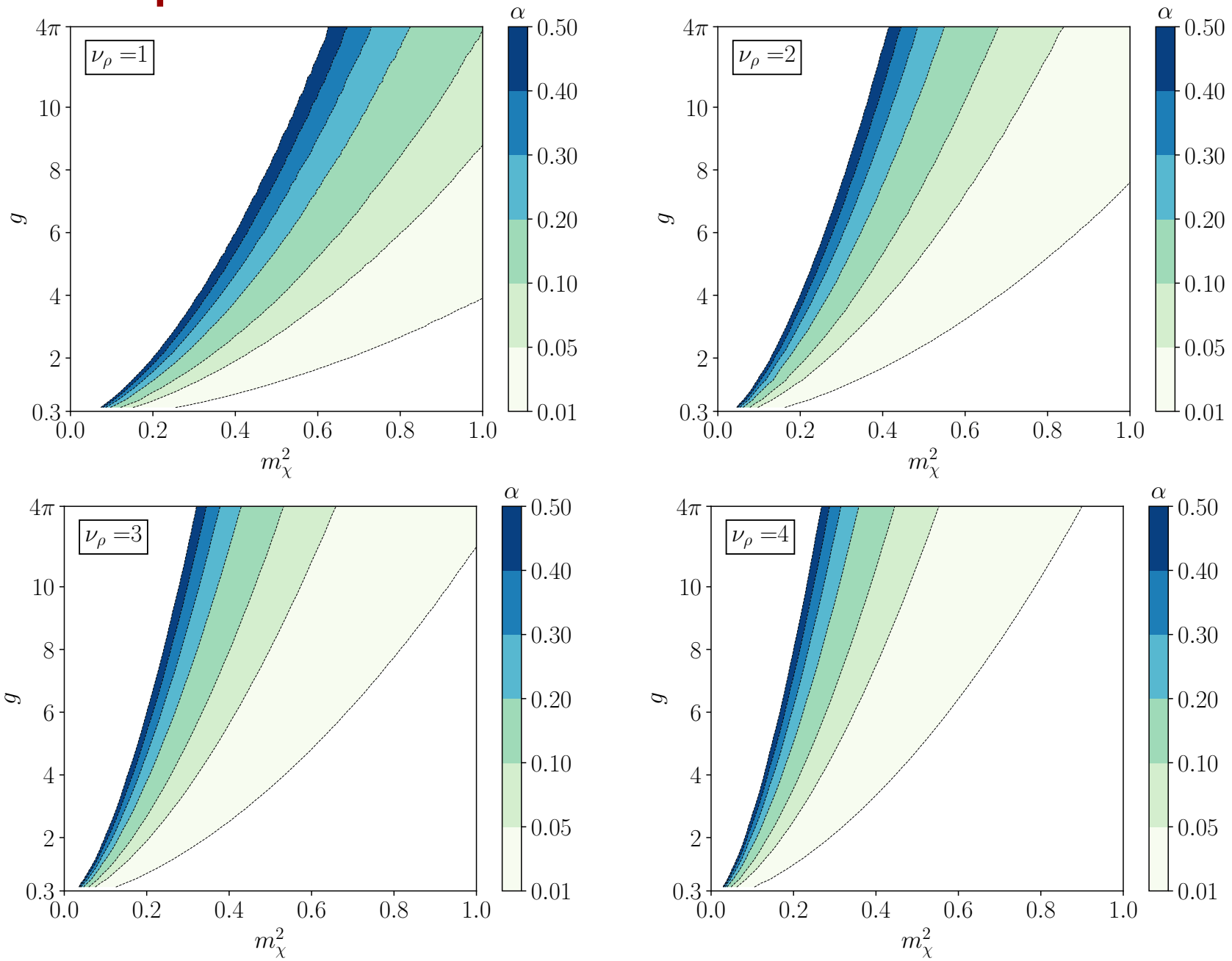

Observational prospect

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

$S_{\text{dS thermal}}$ 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:
$\Delta v_\rho \approx 0.01$ for $f_{\text{NL}} = 1 \Rightarrow \alpha_{\text{min}} \approx 0.01$

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

Conclusion

- Light fields χ during inflation are difficult to detect in cosmological collider through direct interaction with inflaton
- But they can imprint unique de Sitter "thermal" mass correction on a massive field ρ 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 $\mathcal{O}(1)\ \chi - \rho$ coupling and $m_\chi^2 \lesssim H^2$