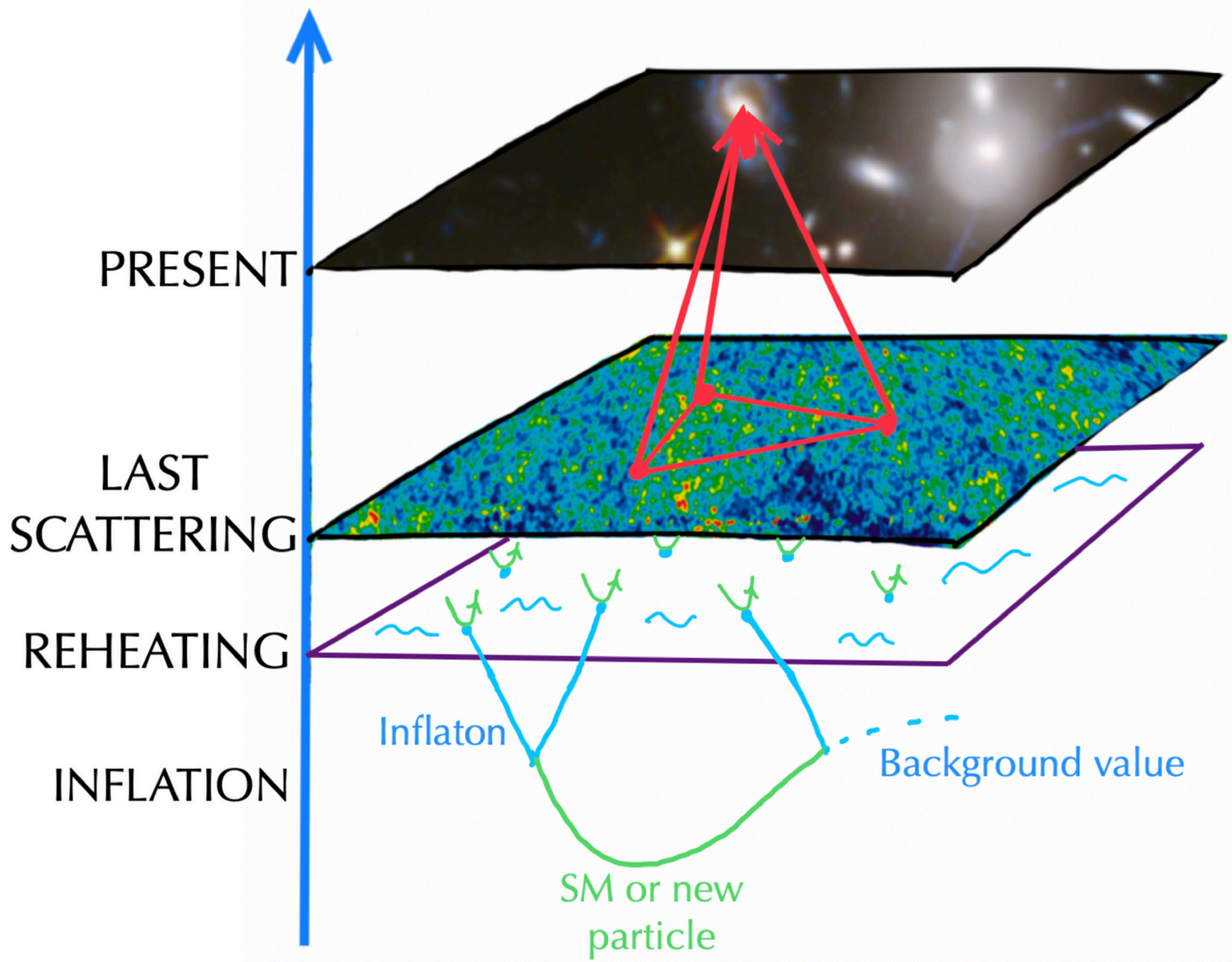
An Effective Cosmological Collider

Amara McCune, amara@physics.ucsb.edu
University of California, Santa Barbara
Fundamental Physics for Future Spectroscopic Surveys

Based on 2401.10976 with
Nathaniel Craig & Soubhik Kumar

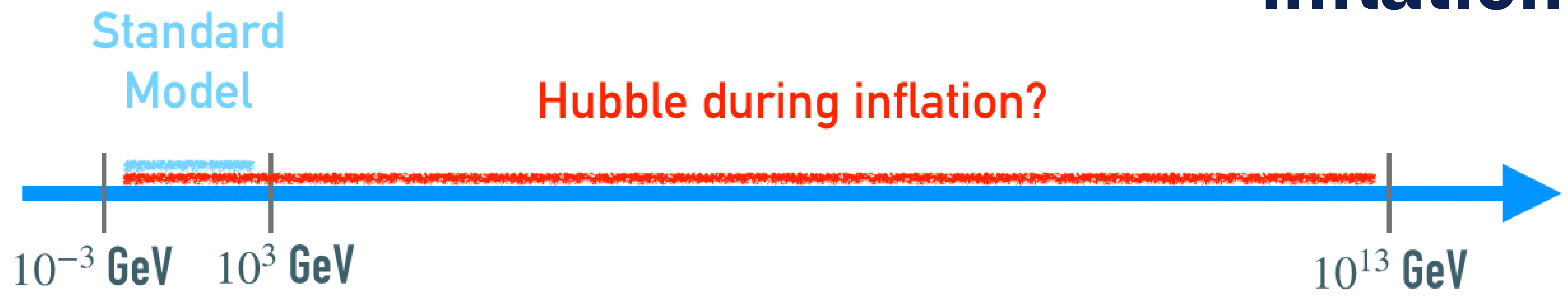

PRESENT
LAST SCATTERING
REHEATING
INFLATION
Inflaton
Background value
SM or new particle

Inflaton 3 point function has a distinct, oscillatory signature, depends on mass & spin spectra of heavy particles:

$$F \sim e^{-\pi\mu} \frac{1}{k_3^3} \frac{1}{k_1^3} \left(\frac{k_3}{k_1} \right)^{\mu(m)} e^{i\delta(\mu)} + \mathrm{c.c.}$$

with $\mu(m) = \frac{3}{2} + i\sqrt{\frac{m^2}{H^2} - \frac{9}{4}}$

observational "window" for particles with masses of order Hubble during inflation



Probing P and CP Violations on the Cosmological Collider

Tao Liu, Xi Tong, Yi Wang, Zhong-Zhi Xianyu

Continuous Spectrum on Cosmological Collider

Shuntaro Aoki

Disentangling mass spectra of multiple fields in cosmological collider

Shuntaro Aoki, Masahide Yamaguchi

The cosmological collider in R^2 inflation

Yi-Peng Wu

Prospects for Cosmological Collider Physics

P. Daniel Meerburg, Moritz Münchmeyer, Julian B. Muñoz, Xingang Chen

Cosmological Collider Physics and the Curvaton

Soubhik Kumar, Raman Sundrum

Missing Scalars at the Cosmological Collider

Qianshu Lu, Matthew Reece, Zhong-Zhi Xianyu

Large-Field Inflation and the Cosmological Collider

Matthew Reece, Lian-Tao Wang, Zhong-Zhi Xianyu

Large Spin-2 Signals at the Cosmological Collider

Xi Tong, Zhong-Zhi Xianyu

In Search of Large Signals at the Cosmological Collider

Lian-Tao Wang, Zhong-Zhi Xianyu

Shapes of the Cosmological Low-Speed Collider

Sadra Jazayeri, Sébastien Renaux-Petel, Denis Werth

Gauge Boson Signals at the Cosmological Collider

Lian-Tao Wang, Zhong-Zhi Xianyu

Standard Model Background of the Cosmological Collider

Xingang Chen, Yi Wang, Zhong-Zhi Xianyu

Large-Field Inflation and the Cosmological Collider

Matthew Reece, Lian-Tao Wang, Zhong-Zhi Xianyu

Classical Cosmological Collider Physics and Primordial Features

Xingang Chen, Reza Ebadi, Soubhik Kumar

Light Scalars at the Cosmological Collider

Priyesh Chakraborty, John Stout

The Scalar Chemical Potential in Cosmological Collider Physics

Arushi Bodas, Soubhik Kumar, Raman Sundrum

Higher Spin Supersymmetry at the Cosmological Collider: Sculpting SUSY Rilles in the CMB

Stephon Alexander, S. James Gates Jr., Leah Jenks, K. Koutrolikos, Evan McDonough

Lots of interest! + connections to BSM physics

How can we perform systematic calculations with the cosmological collider to compare with the results of spectroscopic surveys?

Pertinent operators have mass dimension 5 or higher:

$$\mathscr{L} \supset \sim f\left(\frac{\partial\phi}{\Lambda^2}\right)\mathcal{O}_{SM}$$

The usual EFT tools require careful consideration:

1. We are interested in cosmological correlators at a fixed time slice
2. Computations take place in an inflationary background

Boundary terms from IBP do not necessarily vanish

Field redefinitions may shift the correlator itself

A Gauge-Higgs Example

Consider:

$$\mathscr{L}_0 = (D_\mu H)^\dagger D^\mu H - m^2 |H|^2 - \lambda |H|^4 + \frac{1}{2}\partial^\mu \phi \partial_\mu \phi - \frac{1}{4} Z_{\mu\nu} Z^{\mu\nu}$$

where $D_\mu \equiv \partial_\mu - igZ_\mu$

At dim-5, one could write the operator: $\frac{c_2}{\Lambda}(H^\dagger D^\mu H)(\partial_\mu \phi)$

Find that this operator is redundant

Main Takeaways

1) Systematic treatment of boundary terms

2) Isolates physical effects and uncovers all pertinent operators

3) Provides an EFT organization

Dimension	Operator	Observables
5	$\mathcal{O}_{5,4} = \phi F_{\mu\nu}\tilde{F}^{\mu\nu}$	Loop [87]
6	$\mathcal{O}_{6,1} = (\nabla_\mu\phi)^2\mathcal{H}^\dagger\mathcal{H}$	Tree [39] and Loop [36]
7	$\mathcal{O}_{7,2} = \lvert\mathcal{H}\rvert^2\nabla_\mu\phi\nabla_\nu F^{\nu\mu}$	Loop
	$\mathcal{O}_{7,4} = F_{\mu\nu}\nabla^\mu\phi\nabla_\rho F^{\rho\nu}$	Loop
8	$\mathcal{O}_{8,1} = F_{\mu\nu}F^{\mu\nu}(\nabla_\rho\phi)^2$	Loop [36]
	$\mathcal{O}_{8,2} = F_{\mu\nu}\tilde{F}^{\mu\nu}(\nabla_\rho\phi)^2$	Loop
	$\mathcal{O}_{8,3} = \lvert\mathcal{H}\rvert^4(\nabla_\mu\phi)^2$	Tree and Loop
	$\mathcal{O}_{8,4} = \lvert D_\mu\mathcal{H}\rvert^2(\nabla_\nu\phi)^2$	Loop [36]
	$\mathcal{O}_{8,5} = (D^\mu\mathcal{H})^\dagger D^\nu\mathcal{H}\nabla_\mu\phi\nabla_\nu\phi$	Loop
	$\mathcal{O}_{8,6} = F_{\mu\rho}F^{\nu\rho}\nabla^\mu\phi\nabla_\nu\phi$	Loop
9	$\mathcal{O}_{9,2} = \lvert\mathcal{H}\rvert^2\mathcal{O}_{7,2}$	Loop
	$\mathcal{O}_{9,4} = \lvert\mathcal{H}\rvert^2\mathcal{O}_{7,4}$	Loop
	$\mathcal{O}_{9,5} = \nabla_\nu\phi\nabla^\mu(\mathcal{H}^\dagger\mathcal{H})F_{\mu\alpha}F^{\nu\alpha}$	Loop
	$\mathcal{O}_{9,6} = \mathcal{O}_{5,1}F_{\alpha\nu}F^{\alpha\nu}$	Loop
	$\mathcal{O}_{9,7} = \mathcal{O}_{5,1}F_{\alpha\nu}\tilde{F}^{\alpha\nu}$	Loop
	$\mathcal{O}_{9,8} = \nabla_\nu\phi\nabla_\beta F^{\beta\mu}F_{\mu\alpha}F^{\nu\alpha}$	Loop
	$\mathcal{O}_{9,9} = \mathcal{O}_{5,3}F_{\alpha\nu}F^{\alpha\nu}$	Loop
	$\mathcal{O}_{9,10} = \mathcal{O}_{5,3}F_{\alpha\nu}\tilde{F}^{\alpha\nu}$	Loop
	$\mathcal{O}_{9,11} = \mathcal{O}_{5,1}(\nabla_\mu\phi)^2$	Tree and Loop
	$\mathcal{O}_{9,12} = \mathcal{O}_{5,3}(\nabla_\mu\phi)^2$	Tree [39] and Loop
	$\mathcal{O}_{9,13} = \mathcal{O}_{5,1}\lvert D_\mu\mathcal{H}\rvert^2$	Loop
	$\mathcal{O}_{9,14} = \nabla_\mu\phi\nabla^\nu(\mathcal{H}^\dagger\mathcal{H})(D^\mu\mathcal{H})^\dagger D_\nu\mathcal{H}$	Loop
	$\mathcal{O}_{9,15} = \mathcal{O}_{5,3}\lvert D_\mu\mathcal{H}\rvert^2$	Loop
	$\mathcal{O}_{9,16} = \nabla_\nu\phi\nabla_\alpha F^{\alpha\mu}(D^\nu\mathcal{H})^\dagger D_\mu\mathcal{H}$	Loop
	$\mathcal{O}_{9,18} = \nabla_\nu\nabla_\mu\phi\nabla_\alpha F^{\alpha\mu}\nabla_\beta F^{\beta\nu}$	Loop
	$\mathcal{O}_{9,19} = \nabla_\nu\nabla_\mu\phi\nabla_\alpha F^{\alpha\mu}\nabla^\nu(\mathcal{H}^\dagger\mathcal{H})$	Loop

Future Directions

1) Methods may be generalized to other sectors & models of inflation

2) Precise computation of effects at loop order

3) Extension of flat-space EFT methods

Summary

1) Establishing a minimal operator basis is essential for full utilization of the cosmological collider

2) Standard assumptions of EFT construction in flat space require reconsideration

3) There are lots of opportunities for cross-collaboration with effective field theorists & cosmologists!