

Second EuCAPT Symposium
May 2022, 25th

Based on: **[Lucas Pinol 2020]**
J. Cosm. & Astro. Phys. 04(2021)048

[Lucas Pinol, Aoki, Renaux-Petel, Yamaguchi 2021]
ArXiv:2112.05710



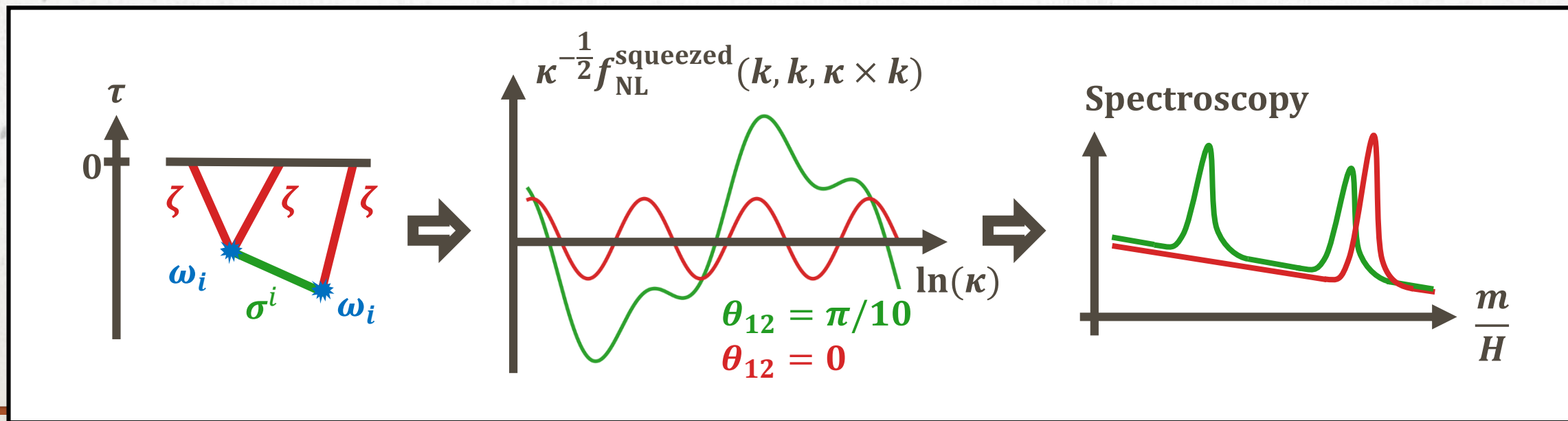
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INFLATIONARY FLAVOR OSCILLATIONS AND THE COSMIC SPECTROSCOPY

PS: it will be 6 min long sorry



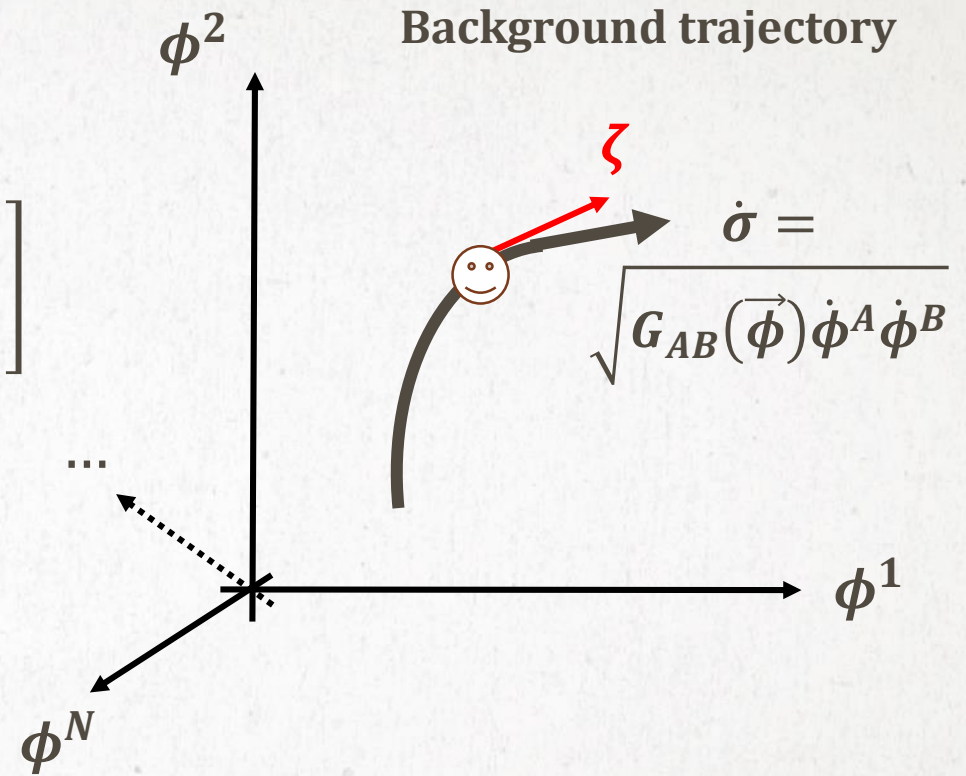
Other topics of research: Multifield stochastic inflation in phase space, multi-species reheating, anisotropies of the SGWB...

INFLATIONARY FLAVOR AND MASS BASES

Multifield inflation with non-canonical kinetic terms:

$$S = \int d^4x \sqrt{-g} \left[\frac{R}{2} - \sum_{A,B} g^{\mu\nu} \mathbf{G}_{AB}(\vec{\phi}) \partial_\mu \phi^A \partial_\nu \phi^B - V(\vec{\phi}) \right]$$

- Both **potential** and **kinetic** interactions: **very generic**
- Any number N of scalar fields
- Perturbation theory: $\phi^A(t, \vec{x}) = \bar{\phi}^A(t) + \delta\phi^A(t, \vec{x}) + \dots$



To compute non-Gaussianities: define gauge-invariant variables, expand the action at cubic order, make IBPs, etc.

INFLATIONARY FLAVOR AND MASS BASES

[Lucas Pinol 2020]

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Quadratic action for the extra fluctuations:

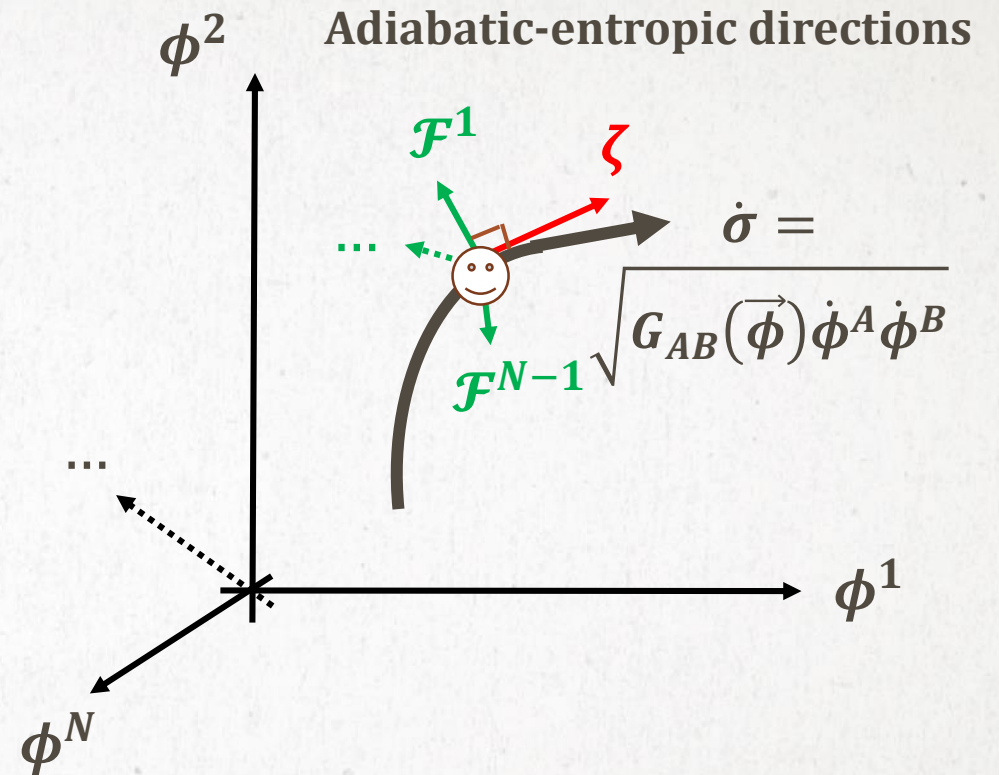
(Also the cubic action is computed)

ζ

The curvature perturbation

$\mathcal{F}^1, \dots, \mathcal{F}^{N-1}$

The entropic/isocurvature perturbations



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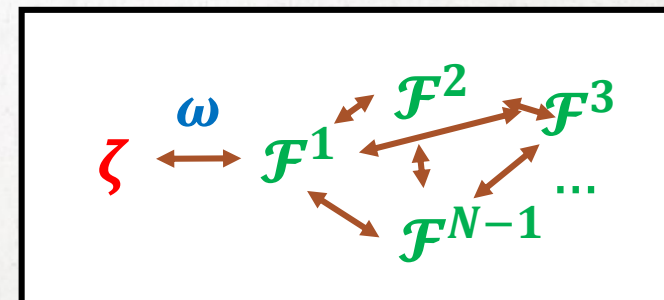
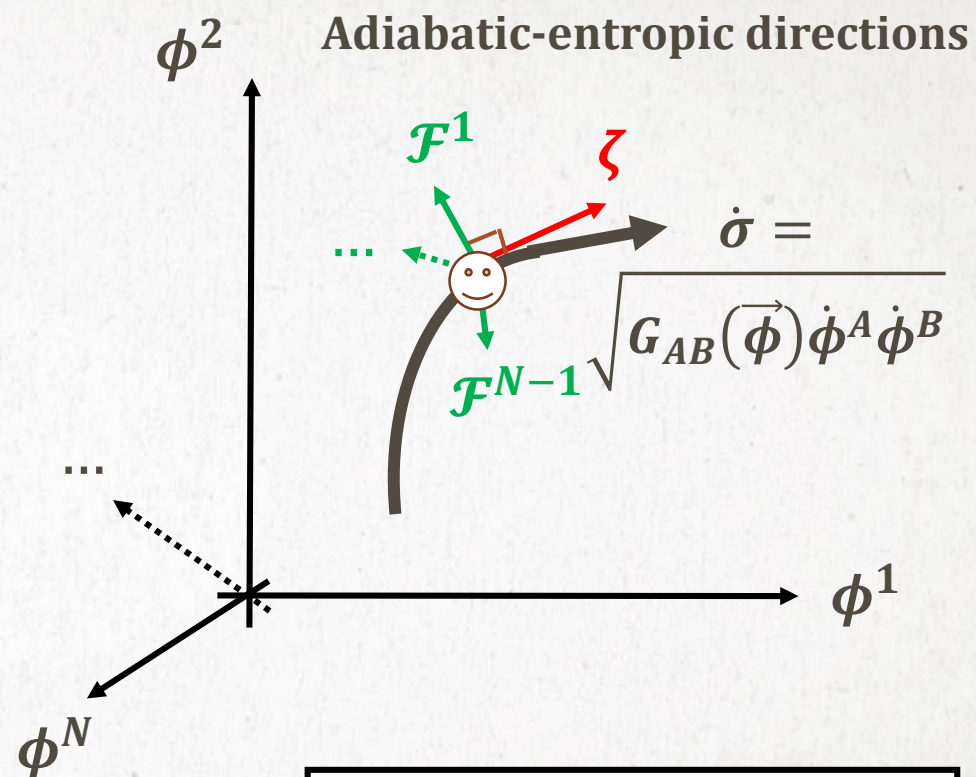
Quadratic action for the extra fluctuations:

$$\mathcal{L}_{\text{flavor}}^{(2)} = \frac{a^3}{2} \left[\delta_{\alpha\beta} \left(\dot{\mathcal{F}}^\alpha \dot{\mathcal{F}}^\beta - \frac{\partial \mathcal{F}^\alpha \partial \mathcal{F}^\beta}{a^2} \right) - \underline{M_{\alpha\beta}^2 \mathcal{F}^\alpha \mathcal{F}^\beta} \right] + 4 \sqrt{2\epsilon} M_{\text{Pl}} \omega \delta_{\alpha 1} \mathcal{F}^\alpha \dot{\zeta}$$

- **Non-trivial mass matrix mixing**
- **Only the first extra field \mathcal{F}^1 is coupled to ζ :
portal field + sterile sector**

Flavor basis: the one in which interactions are specified

Diagonalization: $M_{\alpha\beta} = (OmO^T)_{\alpha\beta}$ and $\mathcal{F}^\alpha = O^\alpha_i \sigma^i$



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Quadratic action for the extra fluctuations:

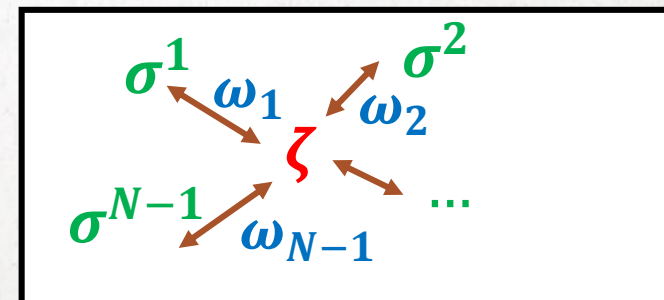
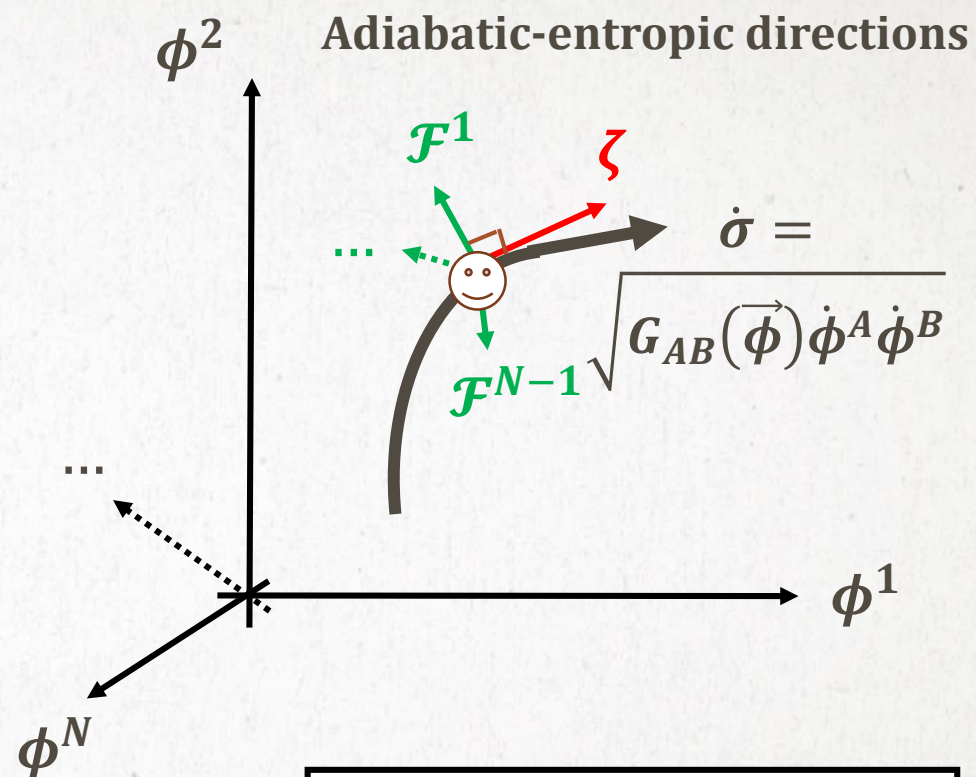
$$\mathcal{L}_{\text{mass}}^{(2)} = \frac{a^3}{2} \left[\delta_{ij} \left(\dot{\sigma}^i \dot{\sigma}^j - \frac{\partial \sigma^i \partial \sigma^j}{a^2} \right) - \sum_i \underline{m_i^2 \sigma_i^2} \right] + 4 \sqrt{2\epsilon} M_{\text{Pl}} \omega O^1_i \sigma^i \zeta$$

- Well-defined masses
- All mass eigenstates are coupled to ζ with:

$$\omega_i = \omega O^1_i \text{ with } \mathcal{F}^1 = O^1_i \sigma^i$$

Mass basis: the one in which masses are specified

Diagonalization: $M_{\alpha\beta} = (OmO^T)_{\alpha\beta}$ and $\mathcal{F}^\alpha = O^\alpha_i \sigma^i$



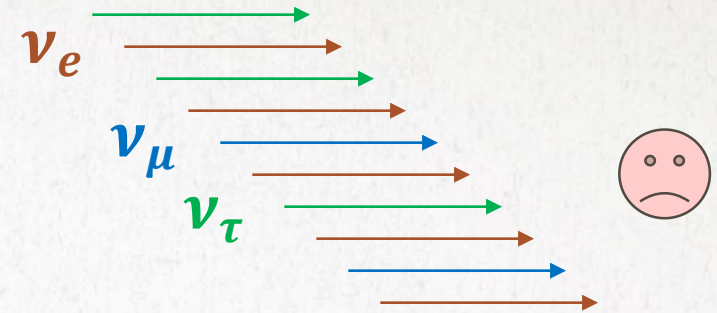
ANALOGY WITH NEUTRINO OSCILLATIONS



This is the Sun

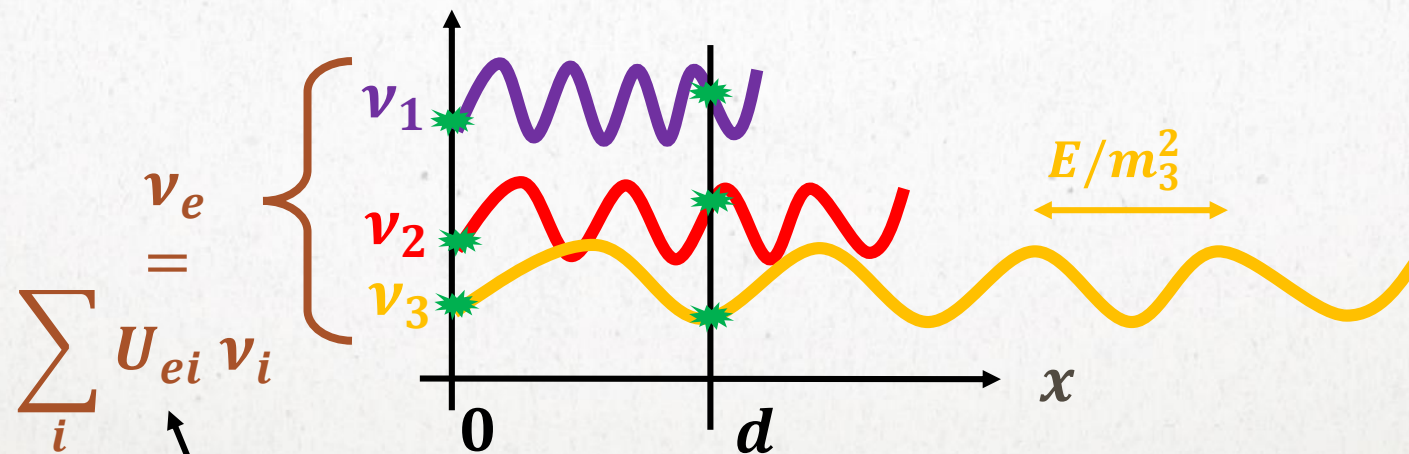
It is emitting electronic neutrinos

NO INTERACTIONS



This is me

I am seeing many less electronic neutrinos



Entries of the PMNS matrix: mixing angles

PMNS stands for Pontecorvo-Maki-Nakagawa-Sakata:
try to pronounce it ten times in a row

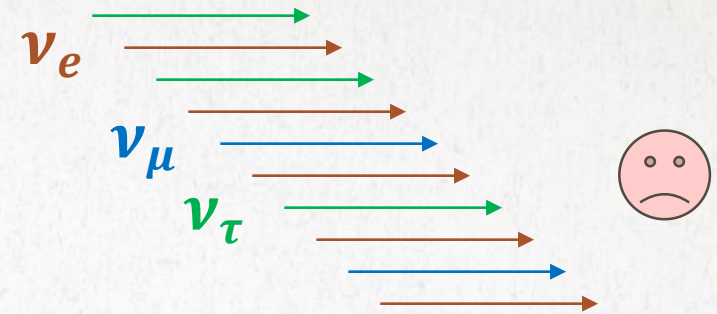
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For us, \mathcal{F}^α are the flavor eigenstates and σ_i the free fields: the mass eigenstates.

In particular: $\mathcal{F}^1 = \sum_i O^1_i \sigma_i$ with $O^1_i = [\cos(\theta_{12})\cos(\theta_{13}), \sin(\theta_{12})\cos(\theta_{13}), \sin(\theta_{13})]_i$, (3)

Mixing angles if $N_{\text{flavor}} = 3$

Maybe called the PARY matrix one day?

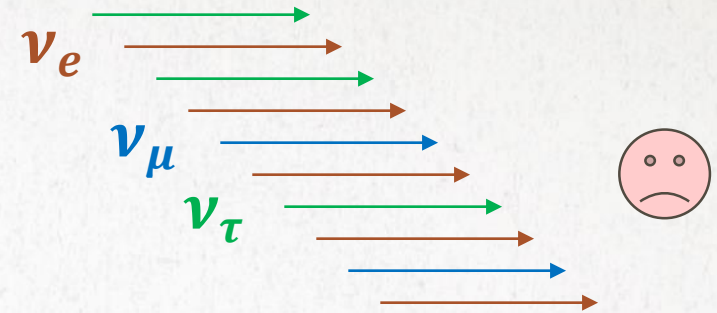
ANALOGY WITH NEUTRINO OSCILLATIONS



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NO INTERACTIONS



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What process equivalent to the missing solar neutrinos may hint towards inflationary flavor oscillations?

BISPECTRUM IN MULTIFIELD INFLATION

The squeezed limit as a cosmological collider

Single-field result:

$$f_{\text{NL}}^{\text{squeezed}} \propto 1 - n_s \ll 1$$

consistency relation

[Maldacena 2003]

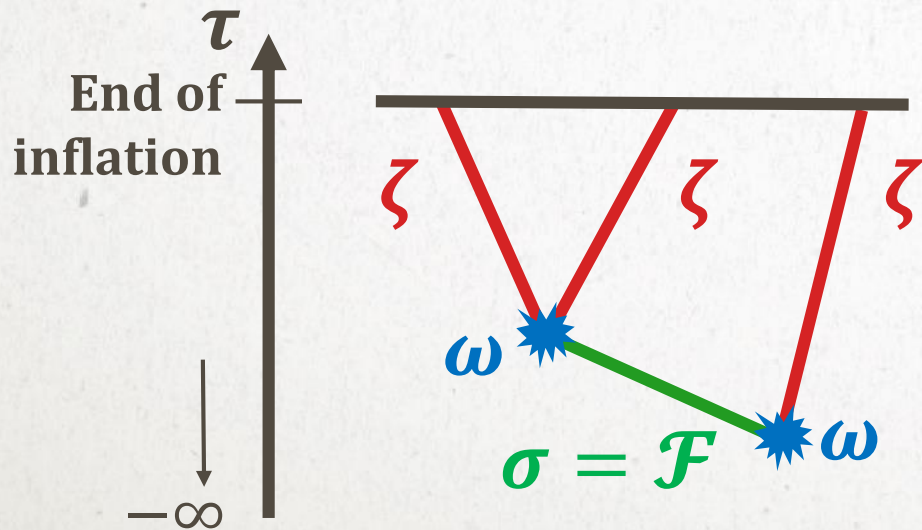
Two-field result:

Usual curvature perturbation ζ + one extra field $\sigma = \mathcal{F}$

[Chen, Wang 2009]

[Noumi, Yamaguchi, Yokoyama 2013]

[Arkani-Hamed, Maldacena 2015]



$$f_{\text{NL}}^{\text{squeezed}} \sim \left(\frac{\omega}{H}\right)^2 e^{-\pi\mu} \cos \left[\mu \log \left(\frac{k_l}{k_s} \right) + \varphi(\mu) \right]$$

Oscillatory pattern: massive particle

$$\mu = \sqrt{\frac{m_\sigma^2}{H^2} - \frac{9}{4}} \text{ the reduced mass}$$

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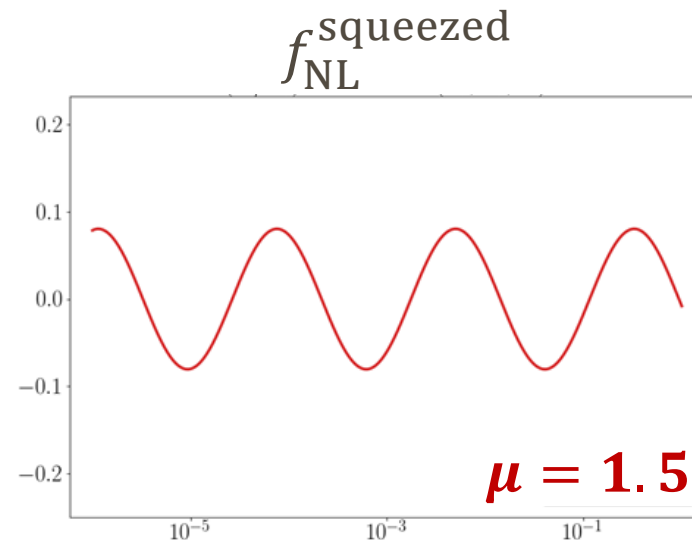
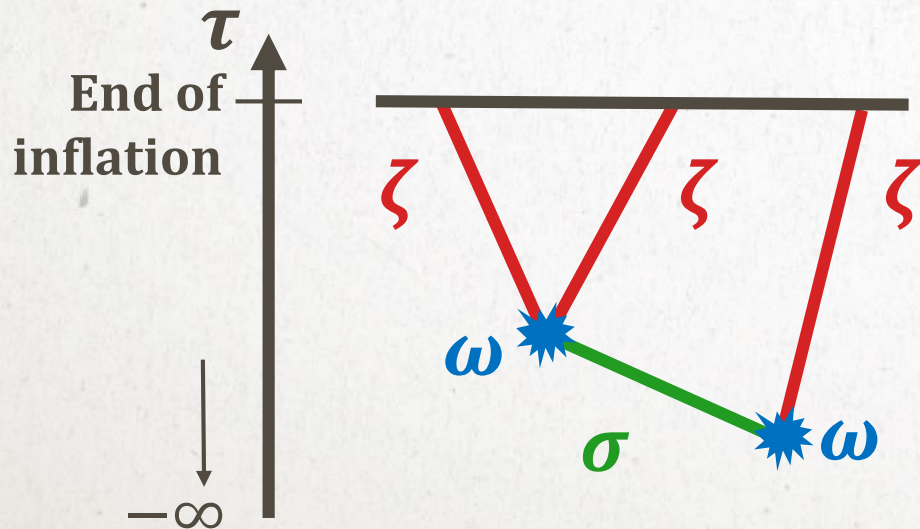
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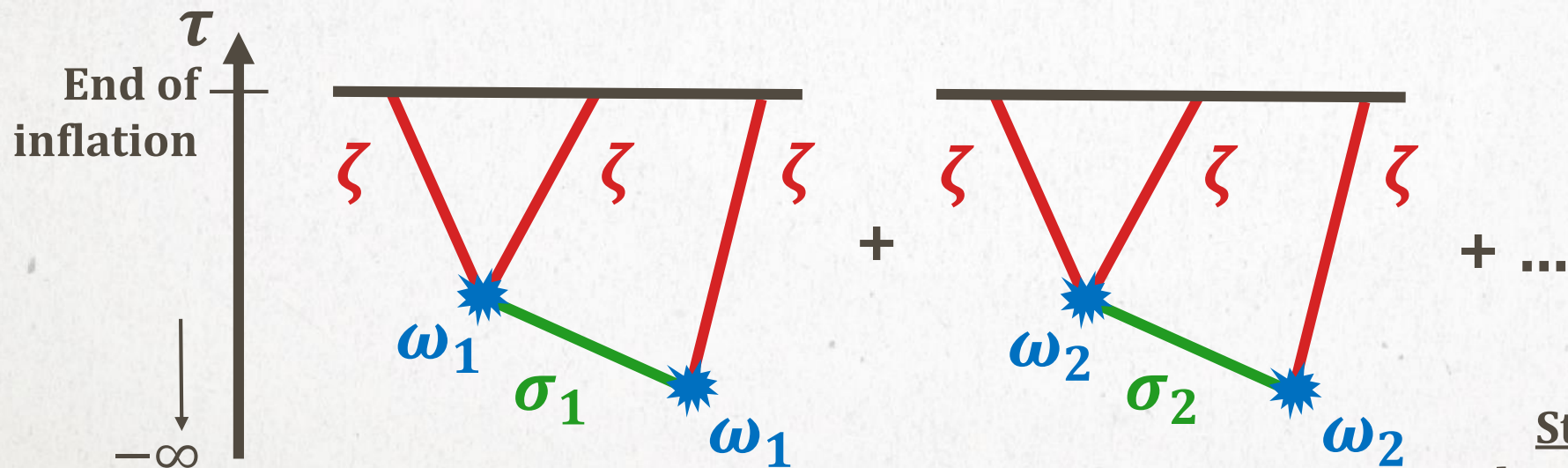
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N-field result



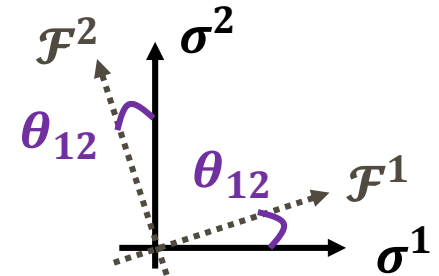
Strength of interactions depend on the mixing angles

$$\omega_i = O^1_i \times \omega$$

BISPECTRUM IN MULTIFIELD INFLATION

- ❖ Three fields: ζ and 2 flavors ($\mathcal{F}^1, \mathcal{F}^2$)

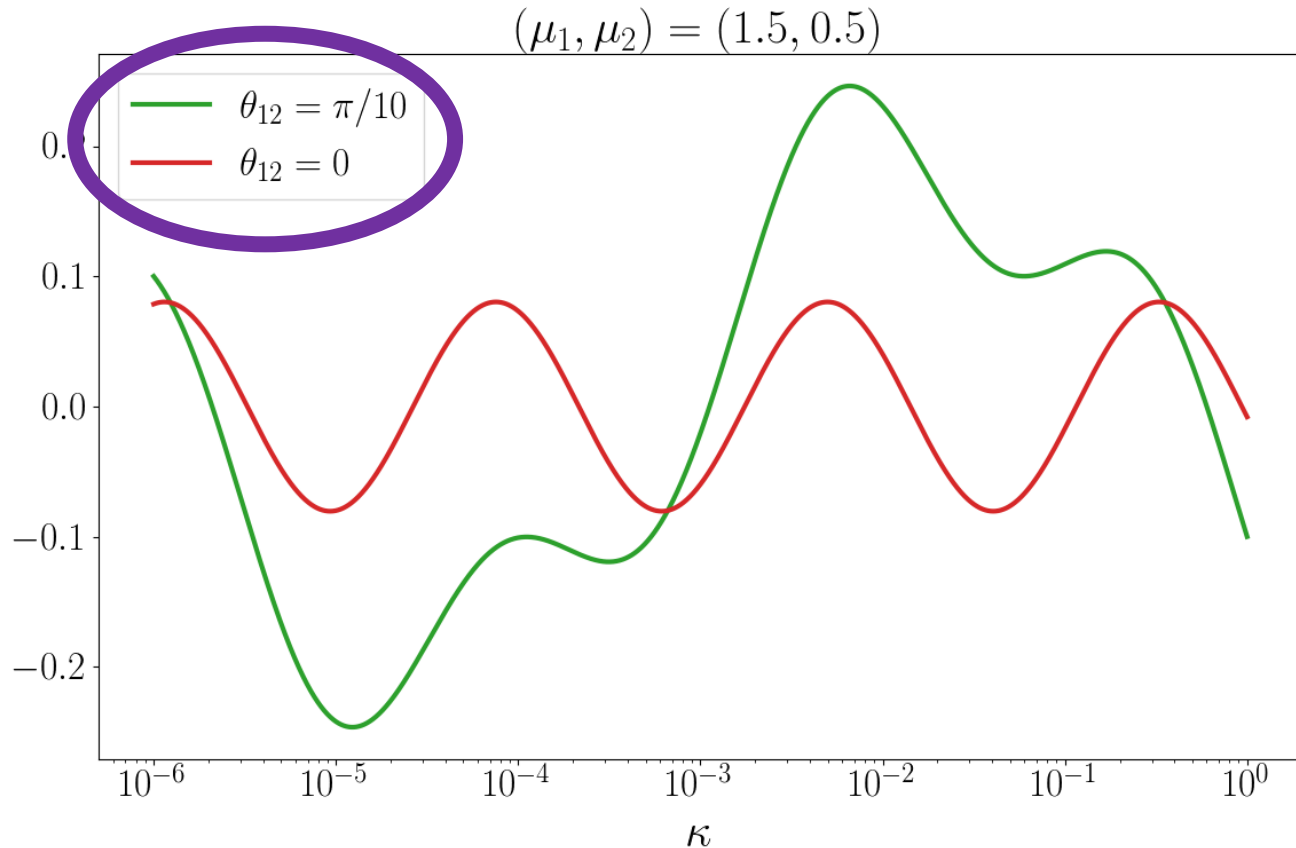
↳ Only one **mixing angle** θ_{12}



- ❖ If $\theta_{12} \in \{0, \pi/2\}$: no mixing

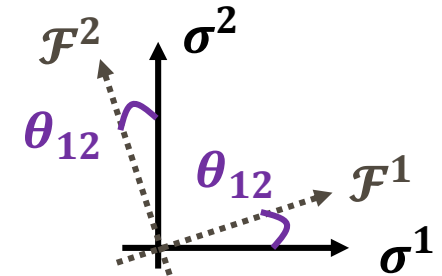
- ❖ If $0 < \theta_{12} < \pi/2$: mixing

BISPECTRUM IN MULTIFIELD INFLATION



❖ Three fields: ζ and 2 flavors ($\mathcal{F}^1, \mathcal{F}^2$)

↳ Only one **mixing angle** θ_{12}



❖ If $\theta_{12} \in \{0, \pi/2\}$: no mixing

↳ **Oscillations** with frequency $\mu_{1,2}$

❖ If $0 < \theta_{12} < \pi/2$: mixing

↳ **Modulated oscillations** with frequencies $\frac{\mu_1 \pm \mu_2}{2}$

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CONCLUSION

Depending on **the mass spectrum and mixing angles**, the squeezed limit of the bispectrum provides a **cosmic spectroscopy**:

