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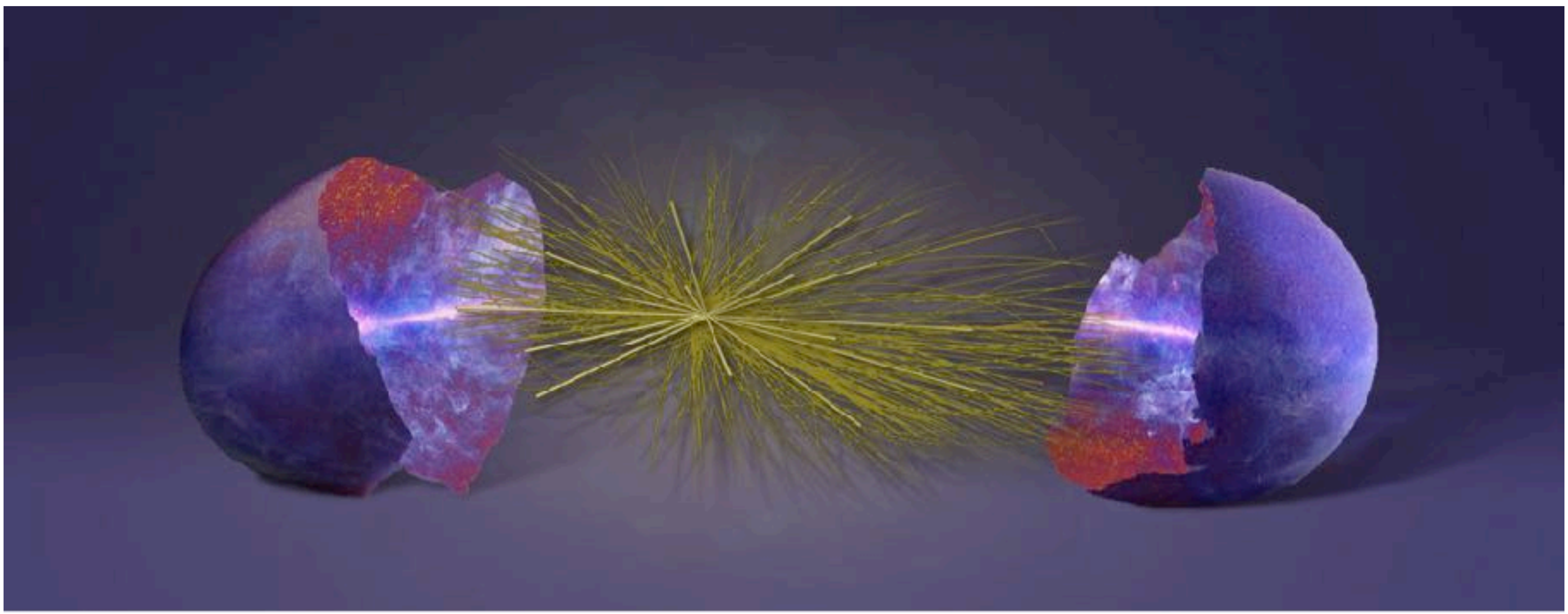
Cosmological Collider Physics



with L. Bordin, P. Creminelli, M. Mirbabayi, and L. Senatore

Motivations

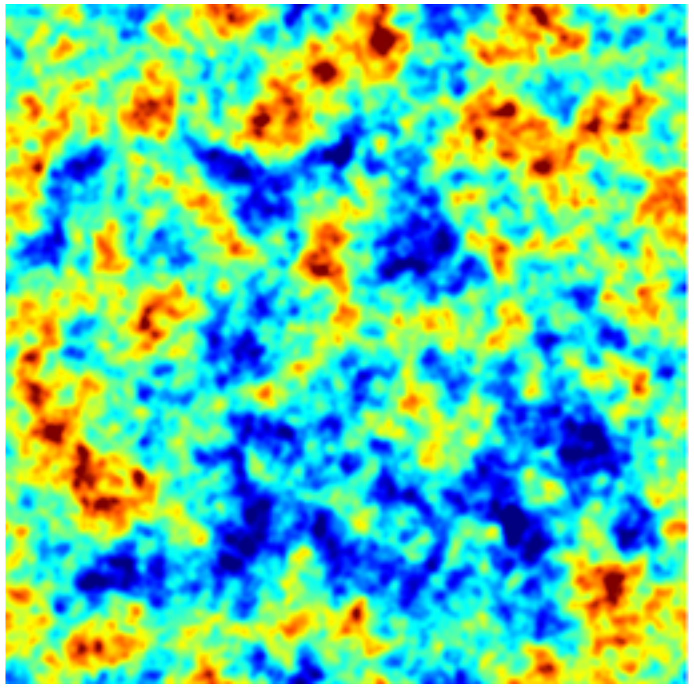
• Inflation: a period of accelerated expansion

Resolves the horizon and the flatness problems

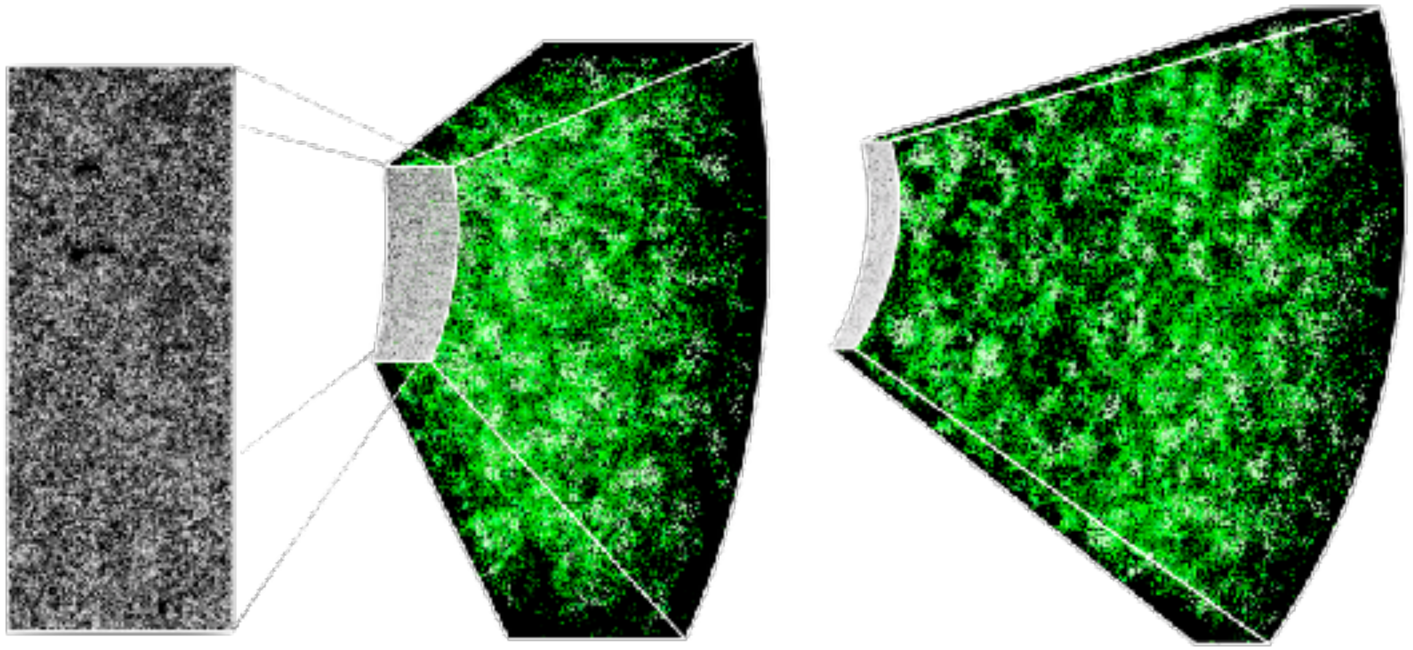
• Requires at least one dynamical field — a “clock” to end inflation

Quantum fluctuations are generated:

CMB



LSS

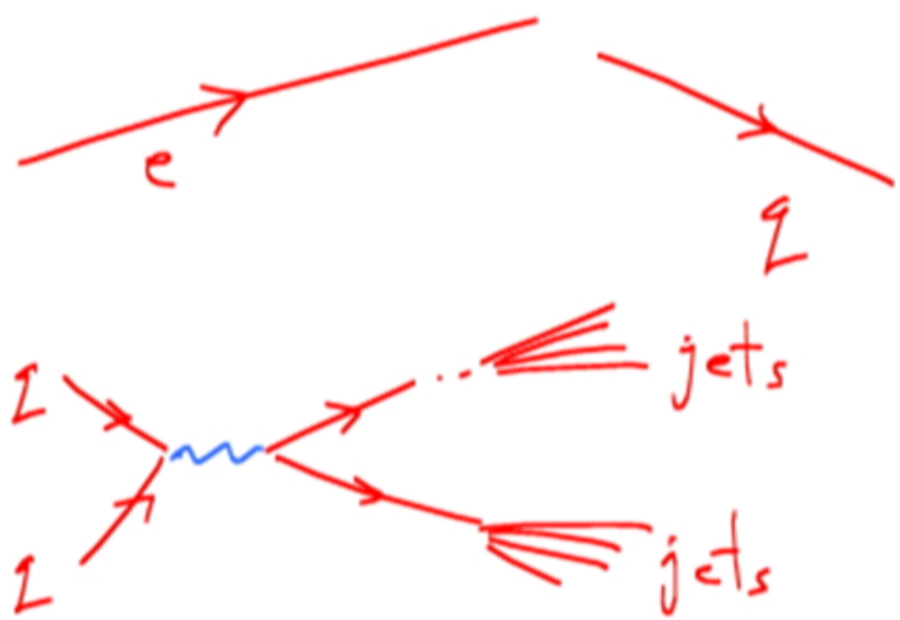


• Details of Inflationary stage are encoded in correlation functions of quantum fluctuations

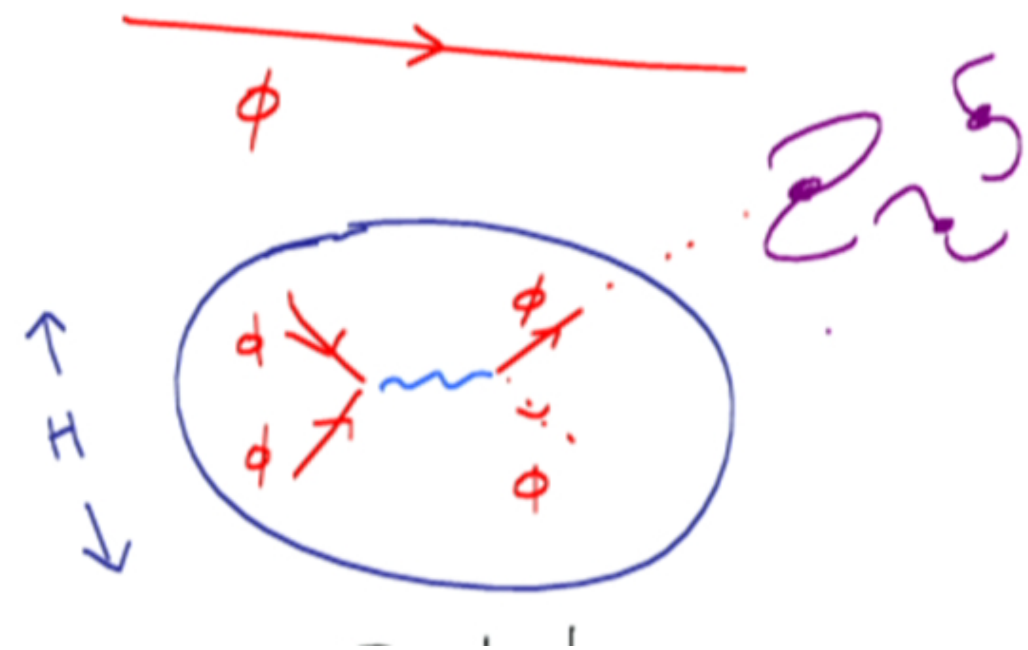
Cosmological Collider Physics

Can we learn anything about fundamental physics from it?

- Energy scale is given by the Hubble rate $H_{\mathrm{inf}} \lesssim 10^{14}$ GeV !
- Could have extra scalars, KK states, stringy states, …



New particles at colliders from signals in scattering amplitudes



New particles from patterns in non-Gaussianities

Chen, Wang '09
Baumann, Green '11
Noumi, Yamaguchi, Yokoyama '12
Arkani-Hamed, Maldacena '15

Non-Gaussianity, f_{NL}, and Observations

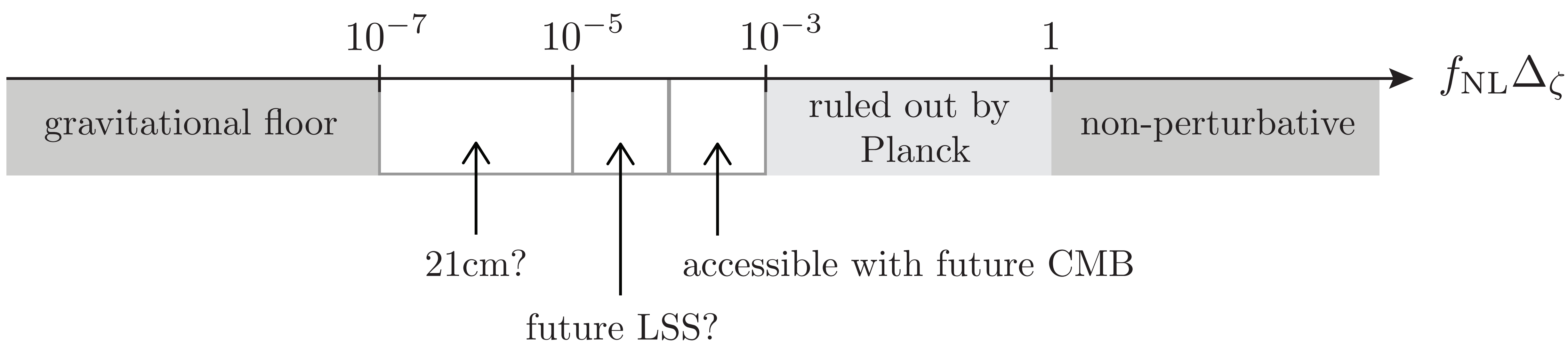
- Inflation predicts fluctuations to be Gaussian (free “clock”)
  with almost scale-invariant power spectrum $(n_s - 1 \approx 0.04)$

$$\langle \zeta_{\vec{k}} \zeta_{\vec{k}'} \rangle = \delta^3(\vec{k} - \vec{k}') \boxed{\frac{\mathcal{A}}{k^{3+n_s-1}}}, \qquad \mathcal{A} \approx 2 \cdot 10^{-9} \equiv \Delta_\zeta^2$$

- 3-point function is subdominant

$$\langle \zeta_{\vec{k}_1} \zeta_{\vec{k}_2} \zeta_{\vec{k}_3} \rangle \sim \delta^3(\vec{k}_1 + \vec{k}_2 + \vec{k}_3)\, f_{NL} \boxed{P_{k_1}} P_{k_3} \sim \mathcal{O}(f_{NL}\, \Delta_\zeta^4)$$

- Gravitational interactions alone produce $f_{NL} \sim (n_s - 1) \sim 10^{-2}$



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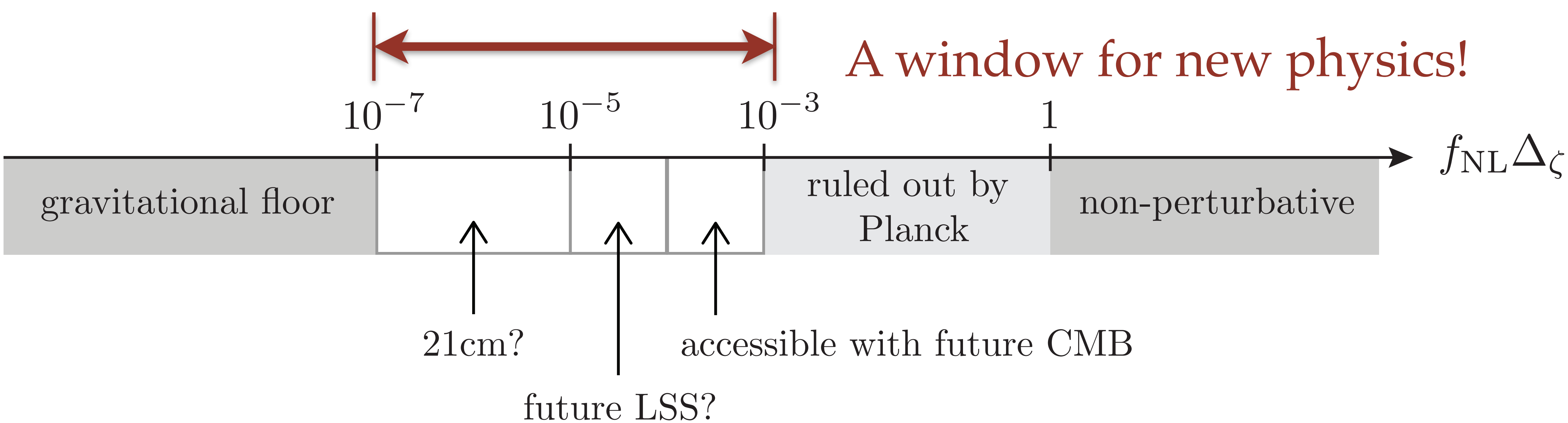
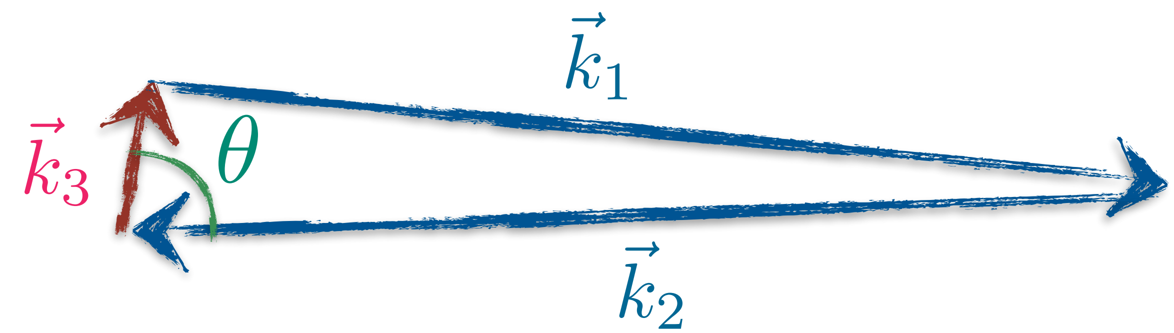


New Physics vs Clock structure, Squeezed limit

Any non-trivial structure of the clock leads to the non-Gaussianities!

- Is there a way to extract the features of new particles?
  To do a spectroscopy — find their masses and spins?!

Squeezed limit: $k_3 \ll k_1 \simeq k_2$



A contribution from a new particle to the 3-point function in the squeezed limit is possible to obtain in a model-independent way:

Arkani-Hamed, Maldacena '15

$$\frac{\langle\zeta\zeta\zeta\rangle}{\langle\zeta\zeta\rangle_{k_{12}}\,\langle\zeta\zeta\rangle_{k_3}} \sim (n_s-1)\,e^{-\pi m/H}\left(\frac{k_3}{k_{12}}\right)^{3/2}\left(\boxed{\left(\frac{k_3}{k_{12}}\right)^{im/H}}+h.c.\right)\boxed{P_s(\cos\theta)}$$

Oscillations in k_3/k_{12}

Angular dependence

Observability of the new physics signatures

The magnitude makes it unobservable in foreseeable future:

$$f_{NL} \sim (n_s - 1)\, e^{-\pi m/H} \left(\frac{k_3}{k_{12}}\right)^{3/2}$$

But all three factors come from the conformal invariance, which is spontaneously broken during Inflation!

- non-conformal couplings to the inflaton:

  no need to pay the price of $(n_s - 1)$ Lee, Baumann, Pimentel '16

- genuinely non-conformal new particles can be light:

  no Boltzmann suppression $e^{-\pi m/H} \sim \mathcal{O}(1)$

  weaker scaling in the squeezed limit $\propto \left(\frac{k_3}{k_{12}}\right)^{1}$

Brodin, Creminelli, Mirbabayi, AK
Senatore '17

Conclusions

- Inflation provides us with a window to new physics at the energy scales up to 10^{14} GeV

- Correlation functions of primordial fluctuations carry the signatures of the new particles, and information about their mass and spin

- In practice, reading the data from the cosmological collider is challenging — need new signatures beyond the scalar bispectrum?

- With the LSS and possibly 21 cm data coming within the next decades it's the right time to think about it.