Implications of BICEP2 for axions.

Andreas Ringwald (DESY)

BICEP 2 Journal Club
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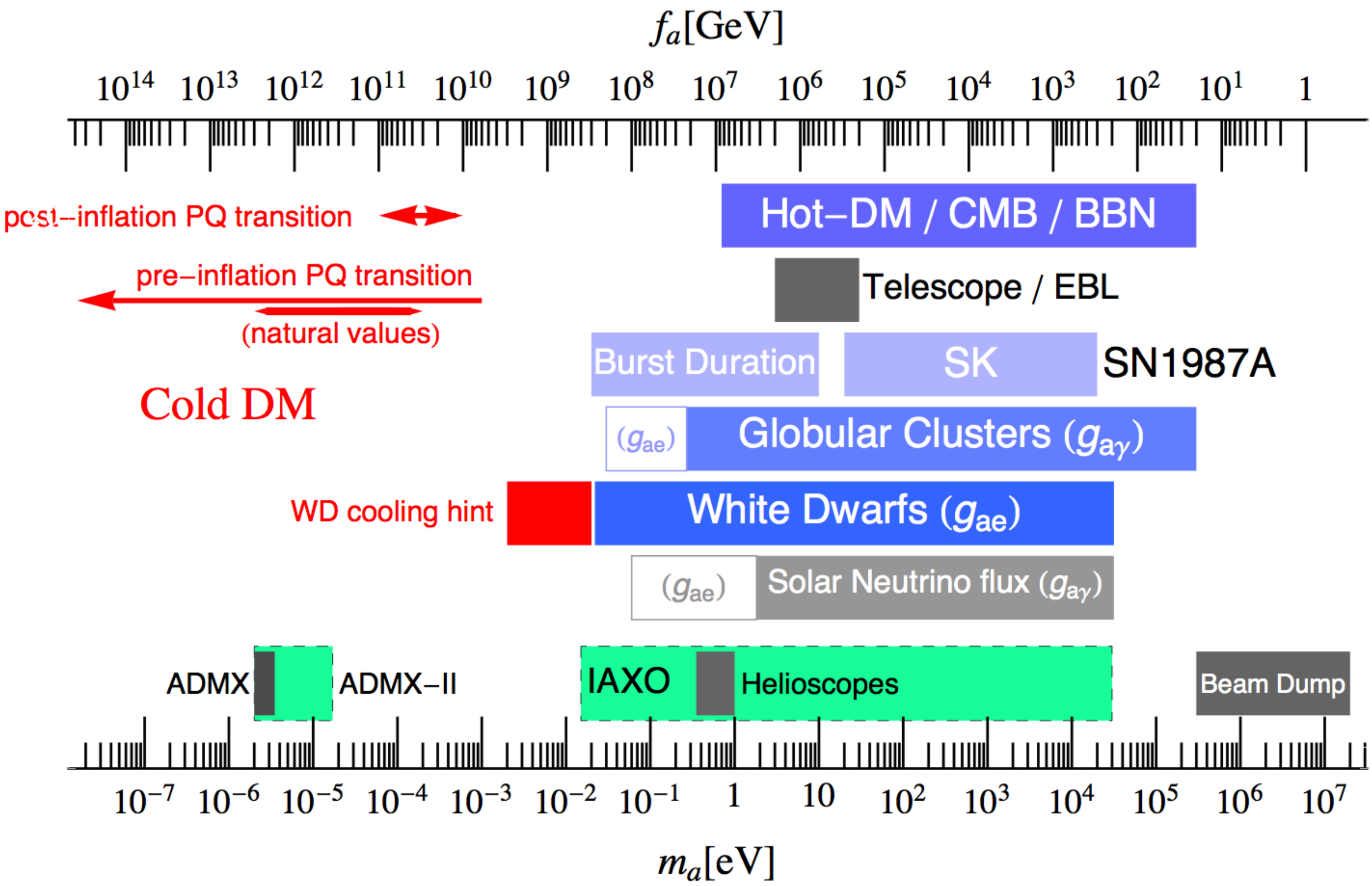
Constraints on axions



Cosmological time evolution of axion field

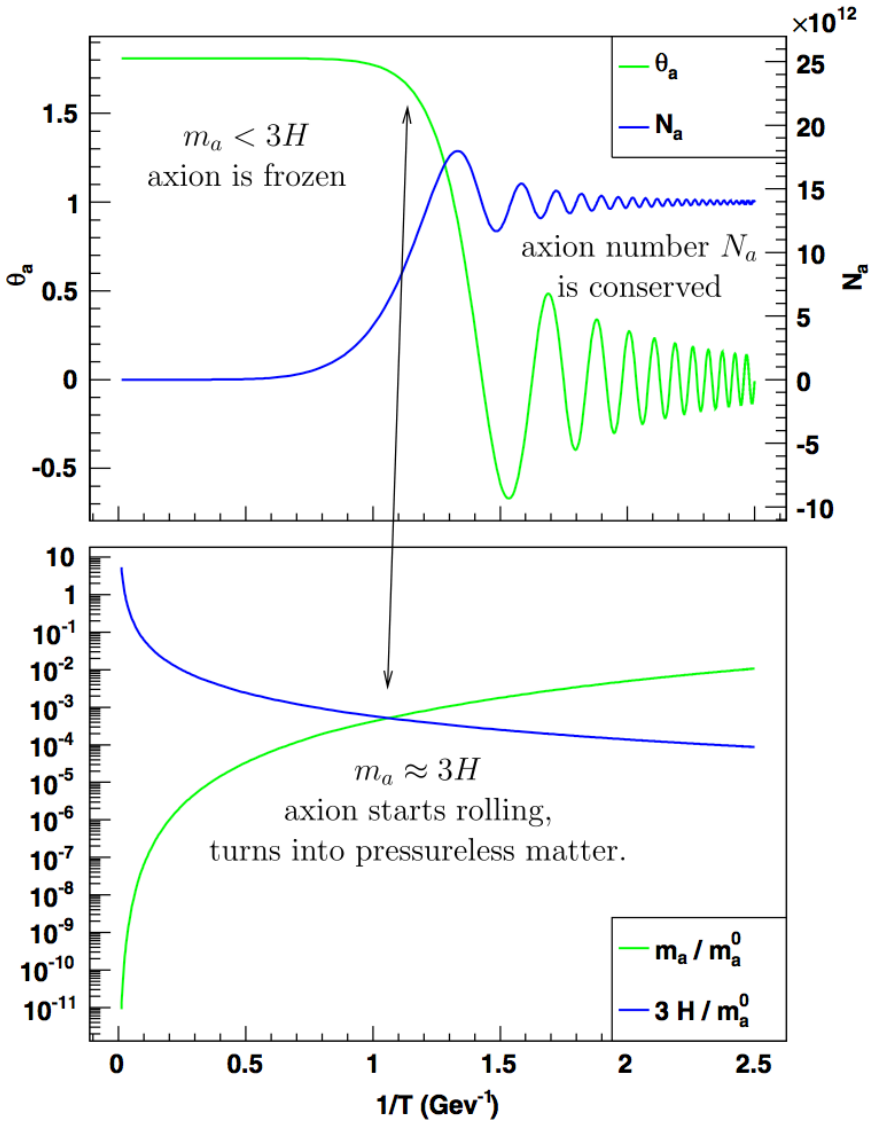
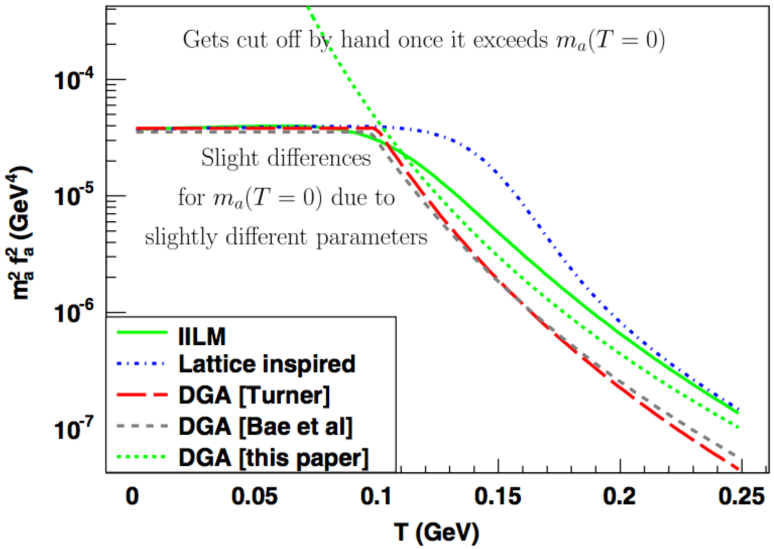
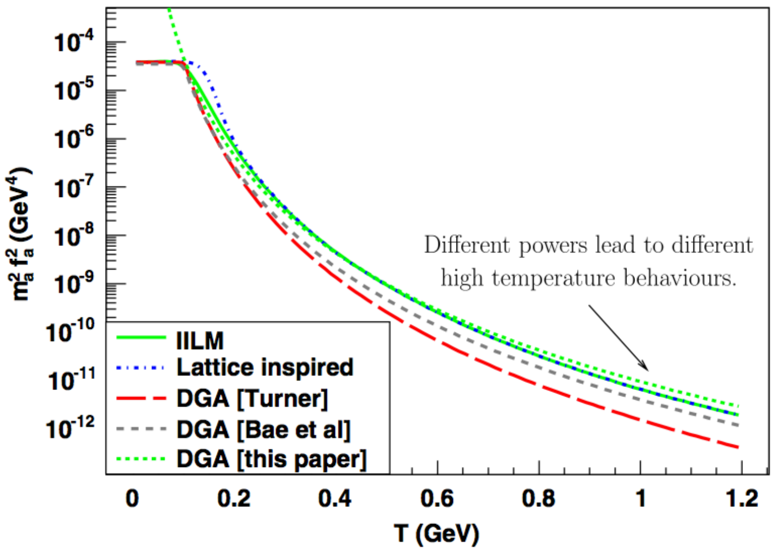


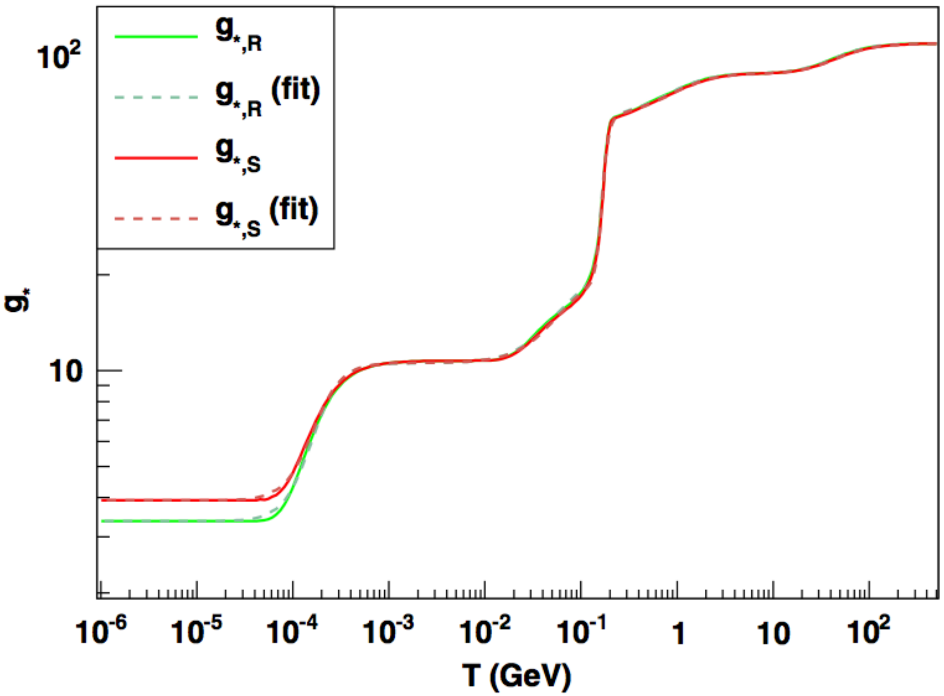
FIG. 4 (color online). As long as the axion Compton wavelength is well outside the horizon, the axion zero mode is frozen; this corresponds to the late-time solution of (26) with m_a neglected. The axion starts to feel the pull of its mass at $m_a \approx 3H$, and evolves to its minimum at $\theta_a = 0$, i.e. the PQ mechanism to solve the strong *CP* problem. After a few oscillations the axion number per comoving volume stays constant as long as the axion mass and the scale factor change slowly (adiabatic approximation). This is then used to extrapolate the result to today.

[Wantz,Shellard PRD 82 (2010) 123508]

Thermal axion mass and effective number of dof

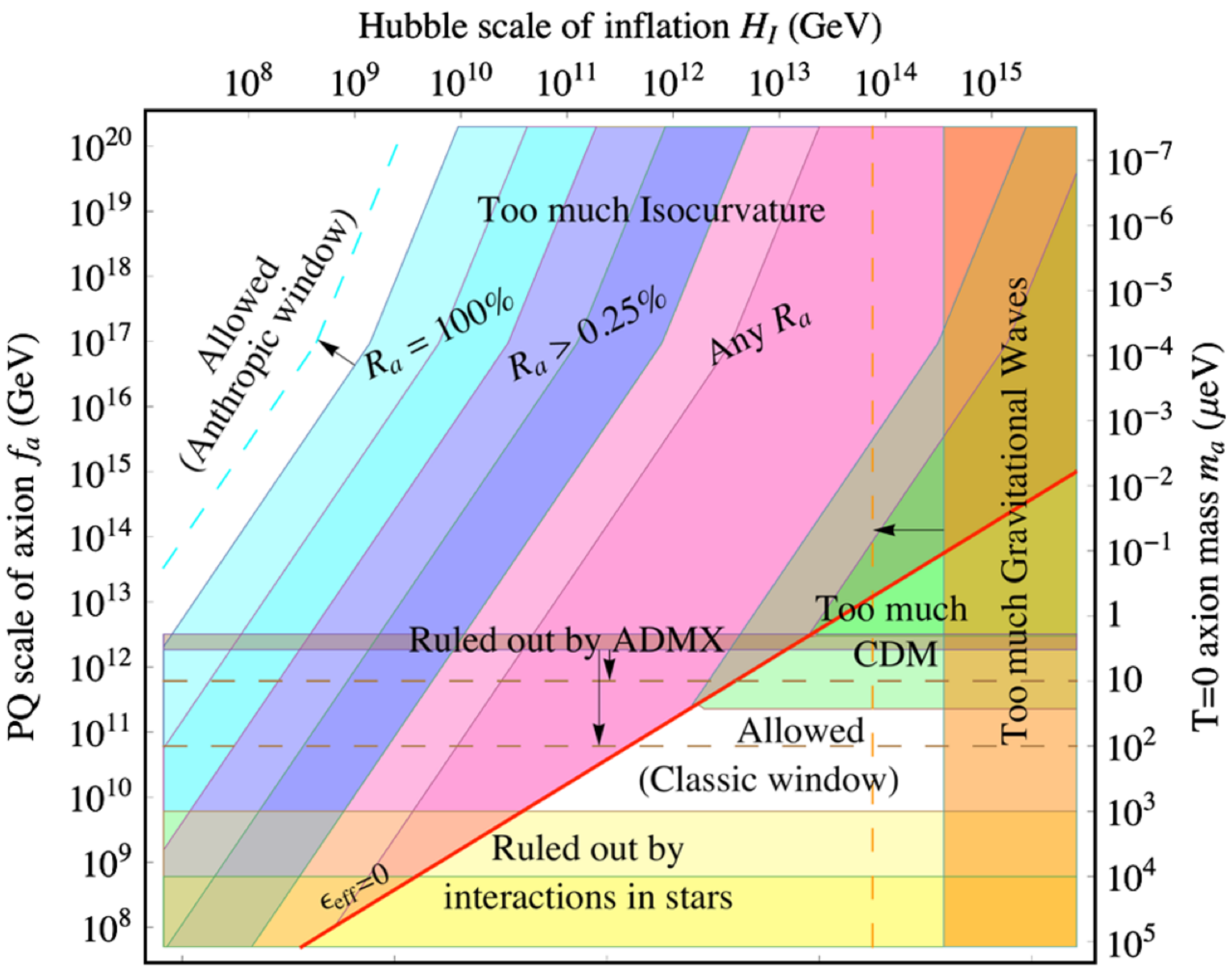






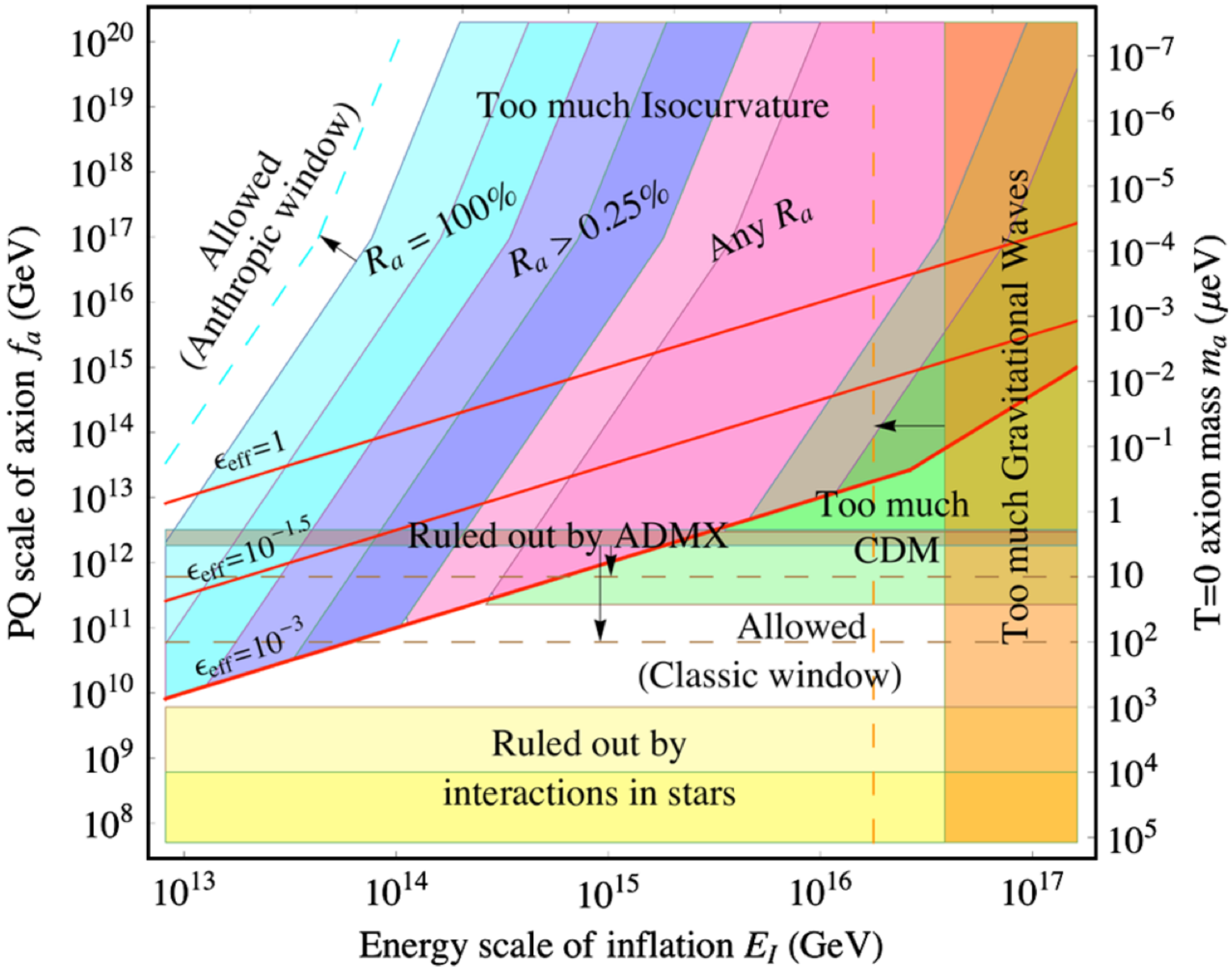
[Wantz,Shellard PRD 82 (2010) 123508]

Constraints for general Hubble scale of inflation



[Hertzberg,Tegmark,Wilczek PRD 78 (2008) 083507]

Constraints for general Hubble scale of inflation



[Hertzberg,Tegmark,Wilczek PRD 78 (2008) 083507]

Early anticipation of BICEP2 implications for axions

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Probing a QCD String Axion with Precision Cosmological Measurements

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ABSTRACT

String and M-theory compactifications generically have compact moduli which can potentially act as the QCD axion. However, as demonstrated here, such a compact modulus can not play the role of a QCD axion and solve the strong CP problem if gravitational waves interpreted as arising from inflation with Hubble constant $H_{\rm inf} \gtrsim 10^{13}$ GeV are observed by the PLANCK polarimetry experiment. In this case axion fluctuations generated during inflation would leave a measurable isocurvature and/or non-Gaussian imprint in the spectrum of primordial temperature fluctuations. This conclusion is independent of any assumptions about the initial axion misalignment angle, how much of the dark matter is relic axions, or possible entropy release by a late decaying particle such as the saxion; it relies only on the mild assumption that the Peccei-Quinn symmetry remains unbroken in the early universe.

Papers on BICEP2 implications for axions

KEK-TH-1711, DESY-14-033, TU-958

Solving the Tension between High-Scale Inflation and Axion Isocurvature Perturbations

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Abstract

The BICEP2 experiment announced the discovery of the primordial B-mode polarization, which determines the Hubble parameter during inflation to be about 10^{14} GeV. Such high inflation scale is in tension with the QCD axion dark matter if the Peccei-Quinn symmetry remains broken during and after inflation, because too large axion isocurvature perturbations would be generated. The axion isocurvature perturbations can be suppressed if the axion acquires a sufficiently heavy mass during inflation. We show that this is realized if the Peccei-Quinn symmetry is explicitly broken down to a discrete symmetry and if the breaking is enhanced during inflation. Such enhancement is possible if during inflation the saxion acquires a vacuum expectation value much larger than in the present vacuum, or if the symmetry breaking operators depend on the inflaton field value. The latter possibility can be implemented easily in a large-field inflation model.

Tensor Detection Severely Constrains Axion Dark Matter

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(Dated: March 18, 2014)

The recent detection of tensor modes by BICEP2 has non-trivial implications for axion dark matter implied by combining the tensor detection with isocurvature constraints from Planck. In this paper the measurement is taken as fact, and its implications considered, though further experimental verification is required. In the simplest inflation models $r = 0.2$ implies $H_I = 1.1 \times 10^{14}$ GeV. If the axion decay constant $f_a > H_I$ then isocurvature constraints effectively rule out the QCD axion as dark matter for $m_a \lesssim 0.06\mu$ eV, contributing only a fraction $\Omega_a/\Omega_d \lesssim 10^{-11}(f_a/10^{16}\text{ GeV})^{5/6}$ (where Ω_i is the fraction of the critical density), with misalignment angle $\theta_i \lesssim 3.1 \times 10^{-8}(f_a/10^{16}\text{ GeV})^{-1/6}$. Implications of this fine tuning are discussed. Constraints on axion-like particles, as a function of their mass and dark matter fraction are also considered. For heavy axions with $m_a \gtrsim 10^{-22}$ eV we find $\Omega_a/\Omega_d \lesssim 10^{-3}$, with stronger constraints on heavier axions. For lighter axions, however, direct constraints from the CMB temperature power spectrum and large scale structure are stronger.

Axion cold dark matter in view of BICEP2 results

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(Dated: March 20, 2014)

The properties of axions that constitute 100% of cold dark matter (CDM) depend on the tensor-to-scalar ratio r at the end of inflation. If $r = 0.20^{+0.07}_{-0.05}$ as reported by the BICEP2 collaboration, then "half" of the CDM axion parameter space is ruled out. Namely, the Peccei-Quinn symmetry must be broken after the end of inflation, and axions do not generate non-adiabatic primordial fluctuations. The cosmic axion density is then independent of the tensor-to-scalar ratio r, and the axion mass is expected to be in a narrow range that however depends on the cosmological model before primordial nucleosynthesis. In the standard ΛCDM cosmology, the CDM axion mass range is $m_a = (71 \pm 2)\,\mu\text{eV}\,(\alpha^{\text{dec}} + 1)^{6/7}$, where α^{dec} is the fractional contribution to the cosmic axion density from decays of axionic strings and walls.

Ways to rescue axions with large f_A

Is there a Peccei–Quinn phase transition?

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Abstract. The nature of axion cosmology is usually said to depend on whether the Peccei–Quinn (PQ) symmetry breaks before or after inflation. The PQ symmetry itself is believed to be an accident, so there is not necessarily a symmetry during inflation at all. We explore these issues in some simple models, which provide examples of symmetry breaking before and after inflation, or in which there is no symmetry during inflation and no phase transition at all. One effect of these observations is to relax the constraints from isocurvature fluctuations due to the axion during inflation. We also observe new possibilities for evading the constraints due to cosmic strings and domain walls, but they seem less generic.

Keywords: dark matter, inflation, axions

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Ways to rescue axions with large f_A

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Axion dark matter and Planck favor non-minimal couplings to gravity ☆

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ABSTRACT

Constraints on inflationary scenarios and isocurvature perturbations have excluded the simplest and most generic models of dark matter based on QCD axions. Considering non-minimal kinetic couplings of scalar fields to gravity substantially changes this picture. The axion can account for the observed dark matter density avoiding the overproduction of isocurvature fluctuations. Finally, we show that assuming the same non-minimal kinetic coupling to the axion (dark matter) and to the standard model Higgs boson (inflaton) provides a minimal picture of early time cosmology.

Ways to rescue axions with large f_A

KEK-TH-1711, DESY-14-033, TU-958

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