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Flavon inflation

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ABSTRACT

We propose an entirely new class of particle physics models of inflation based on the phase transition associated with the spontaneous breaking of family symmetry responsible for the generation of the effective quark and lepton Yukawa couplings. We show that the Higgs fields responsible for the breaking of family symmetry, called flavons, are natural candidates for the inflaton field in new inflation, or the waterfall fields in hybrid inflation. This opens up a rich vein of possibilities for inflation, all linked to the physics of flavour, with interesting cosmological and phenomenological implications. Out of these, we discuss two examples which realise flavon inflation: a model of new inflation based on the discrete non-Abelian family symmetry group A_4 or Δ_{27}, and a model of hybrid inflation embedded in an existing flavour model with a continuous $SU(3)$ family symmetry. With the inflation scale and family symmetry breaking scale below the Grand Unification Theory (GUT) scale, these classes of models are free of the monopole (and similar) problems which are often associated with the GUT phase transition.

1. Introduction

Although the inflationary paradigm was proposed nearly thirty years ago to solve the horizon and flatness problems [1], it is only relatively recently that its main predictions of flatness and density perturbations have been firmly demonstrated to be consistent with observation [2,3]. However the precise nature of the inflation mechanism remains obscure and several versions of inflation have been proposed, bearing names such as old inflation, new inflation, natural inflation, supernatural inflation, chaotic inflation, hybrid inflation, hilltop inflation, and so on [4]. Furthermore, the relation of any of these mechanisms for inflation to particle physics remains unclear, despite much effort in this direction [4]. Indeed it is not even clear if the "inflaton" (the scalar field responsible for inflation) resides in the visible sector of the theory or the hidden sector.

On the other hand, one of the great problems facing particle physics is the flavour problem, i.e. the origin of the three families of quarks and leptons and their Yukawa couplings responsible for their masses and mixings. In the past decade, the flavour problem has been enriched by the discovery of neutrino mass and mixing, leading to an explosion of interest in this area [5]. A common approach is to suppose that the quarks and leptons are described by some family symmetry which is spontaneously broken at a high energy scale by new Higgs fields called "flavons" [6]. In particular, the approximately tri-bimaximal nature of lepton mixing provides a renewed motivation for the idea that the Yukawa couplings are marshalled by a spontaneously broken non-Abelian family symmetry which spans all three families, for example $SU(3)$ [7], $SO(3)$ [8], or one of their discrete subgroups such as Δ_{27} or A_4 [9]. Furthermore such family symmetries provide a possible solution to the supersymmetric (SUSY) flavour and CP problems [10].

In this Letter we suggest that the phase transition associated with the spontaneous breaking of family symmetry is also responsible for cosmological inflation, a possibility we refer to as *flavon inflation*. We emphasise that flavon inflation does not represent a new mechanism for inflation, but rather a whole class of inflation models associated with the spontaneous breaking of family symmetry. For example, the flavons themselves are natural candidates for inflaton fields in new inflation. Since most of the family symmetry models rely on SUSY, we shall work in the framework of SUSY inflation, with supergravity (SUGRA) effects also taken into account. In family symmetry models there may also be other fields associated with the vacuum alignment of the flavons, often called "driving" superfields, and these can alternatively be considered as candidates for the inflaton, with the flavons being identified as the "waterfall fields" of SUSY hybrid inflation.[1]

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[1] We also refer to this possibility as flavon inflation, since the flavon is involved in inflationary dynamics.

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As we shall show, flavon inflation is exceptionally well suited for driving cosmological inflation. In new and hybrid inflation, the inflationary scale is well known to lie below the GUT scale, causing some tension in models based on GUT symmetry breaking. One advantage of flavon inflation is that the breaking of the family symmetry and hence inflation, can occur below the GUT scale. Of course an earlier stage of inflation may have also occurred at the GUT scale, but it is the lowest scale of inflation that is the relevant one for determining the density perturbations. Another advantage of flavon inflation is that in inflationary models associated with the breaking of a GUT symmetry are often plagued by the presence of magnetic monopoles which tend to overclose the Universe. In the case of flavon inflation, since the family symmetry is completely broken,[2] no monopoles result and therefore the monopole problem is absent, and in addition any unwanted relics associated with the GUT scale breaking are inflated away.

In Section 2 we discuss in general terms how the idea of flavon inflation opens up a rich vein of possible inflationary scenarios, all linked to the physics of flavour, and discuss some of their interesting cosmological and phenomenological implications. In Section 2.1 we briefly review the motivation for family symmetry and flavons. In Sections 2.2 and 2.3 we consider two concrete examples of flavon inflation using flavour models. In the first example we show how new inflation can arise with the flavons in fundamental representations of an A_4 family symmetry group playing the role of inflatons. In the second example, we show how the driving superfields responsible for the vacuum alignment of the flavons can play the role of inflatons, with the flavons being the waterfall fields of hybrid inflation. In Section 3 we discuss possible implications of flavon inflation for cosmology and particle physics. Section 4 concludes the Letter.

2. Family symmetry breaking and inflation

2.1. Family symmetry and flavons

One of the greatest mysteries facing modern particle physics is that of the origin of quark and lepton masses and mixings. In the Standard Model (SM) they arise from Yukawa matrices and (in the see-saw extended SM) right-handed neutrino Majorana masses. In order to understand the origin of fermion masses and mixing, a common approach is to assume that the SM is extended by some horizontal family symmetry G_F, which may be continuous or discrete, and gauged or global. It must be broken completely, apart from possibly remaining discrete symmetries, at some high energy scale in order to be phenomenologically consistent, and such a symmetry breaking requires the introduction of new Higgs fields called flavons, ϕ, whose vacuum expectation values (vevs) break the family symmetry $\langle\phi\rangle \neq 0$.

The Yukawa couplings are forbidden by the family symmetry G_F, but once it is broken, effective Yukawa couplings may be generated by non-renormalizable operators involving powers of flavon fields, for example $(\phi/M_c)^n\psi\psi^c H$ leading to an effective Yukawa coupling $\varepsilon^n\psi\psi^c H$ where $\varepsilon = \langle\phi\rangle/M_c$ and ψ, ψ^c are SM fermion fields, H is a SM Higgs field, and M is some high energy mass scale associated with the exchange of massive particles called messengers. Phenomenology requires typically $\varepsilon \sim 0.1$.

If in addition to the family symmetry, the SM gauge group is unified into some GUT gauge group G_{GUT} (for example $SU(5)$, $SO(10)$, etc.) then the high energy theory has the symmetry structure $G_F \times G_{\mathrm{GUT}}$. In such frameworks, the theory has additional constraints arising from the fact that the messenger sector must not spoil unification. This implies that either the messenger sector scale M_c has to be very close to the GUT scale M_{GUT} (thus pushing also the family symmetry breakdown close to the GUT scale) or the messengers must come in complete GUT representations, leading to consequences for low energy phenomenology. Assuming that the flavon sector is responsible for inflation provides additional information on the scale of family symmetry breaking, as we now discuss in the framework of two examples.

2.2. Example 1: Flavon(s) as inflaton(s)

The first example we discuss is where the flavon plays the role of the inflaton in a new inflation model, similar to the one discussed in [11]. However, we make use of the fact that when the inflatons are representations of family symmetry groups instead of GUT groups, new possibilities for inflation models arise. To be more explicit, in the considered class of inflation models, in addition to the invariant combination of fields $(\bar{\phi}\phi)^n/M_*^{2n-2}$ (with ϕ and $\bar{\phi}$ being two fields in conjugate representations) studied in [11] we can now write any combination of family-symmetry-invariant fields. For example with a non-Abelian discrete family symmetry A_4 or Δ_{27}, superpotentials of the form

$$W = \kappa S\left[\frac{(\phi_1\phi_2\phi_3)^n}{M_*^{3n-2}} - \mu^2\right] \tag{2.1}$$

with $n \geqslant 1$ can appear, since for fields $\phi = (\phi_1, \phi_2, \phi_3)$, $\psi = (\psi_1, \psi_2, \psi_3)$ and $\chi = (\chi_1, \chi_2, \chi_3)$ each in the fundamental triplet $\underline{3}$ representation of A_4 or Δ_{27}, the combination $\{\phi_1\psi_2\chi_3 +$ permutations$\}$ forms an invariant. Thus the above combination $\phi_1\phi_2\phi_3$ corresponds to a particular A_4 or Δ_{27} invariant $\phi^3 = \phi_1\phi_2\phi_3$. Without loss of generality the Yukawa coupling κ can be set equal to unity as in [11]. At the global minimum of the potential the ϕ_i components get vevs of order $M = M_*(\mu/M_*)^{2/3n}$.

In the following we analyse the phenomenological predictions of this class of models. We assume a Kähler potential of the non-minimal form (analogous to [11])

$$K = |S|^2 + |\phi|^2 + \kappa_2\frac{|S|^2|\phi|^2}{M_{\mathrm{Pl}}^2} + \kappa_1\frac{|\phi|^4}{4M_{\mathrm{Pl}}^2} + \kappa_3\frac{|S|^4}{4M_{\mathrm{Pl}}^2} + \cdots \tag{2.2}$$

and study the supergravity F-term scalar potential,[3] which is given by

$$V = e^{K/M_{\mathrm{Pl}}^2}\left[K^{i\bar{j}}D_iWD_{\bar{j}}\bar{W} - 3\frac{|W|^2}{M_{\mathrm{Pl}}^2}\right], \tag{2.3}$$

where $D_iW = \partial_iW + \frac{W}{M_{\mathrm{Pl}}^2}\partial_iK$ and $K^{i\bar{j}} = (\partial_i\partial_{\bar{j}}K)^{-1}$. In order to study this potential, we assume $S \ll M_{\mathrm{Pl}}$ and $\phi_i \ll M \ll M_{\mathrm{Pl}}$, where M_{Pl} is the reduced Planck mass $M_{\mathrm{Pl}} = (8\pi G_N)^{-1/2} \sim 10^{18}$ GeV. During inflation, we consider the case in which the driving field S acquires a large mass and therefore goes rapidly to a zero field value (which can be achieved by choosing $\kappa_3 < -1/3$ such that it is heavier than the Hubble scale [11]). Furthermore, we focus on the situation in which the component fields ϕ_i start moving from close to zero (the local maximum of the potential) and roll slowly towards the true minimum of the potential where $\phi_i \sim M$ (vacuum dominated inflation [13]). It is possible to show that a generic inflationary trajectory occurs when all components, ϕ_i, of the triplet field are equal. Therefore, we concentrate on this

[2] We note that if at the lowest order in the effective operator expansion some discrete symmetries remain, these are broken by higher order effects. Possibly created domain wall networks from such remaining discrete symmetries are therefore in general unproblematic, because they are effectively blown away by the pressure generated by these higher-dimensional operators.

[3] Since A_4 is a discrete symmetry, there are no D-term contributions to the potential.

trajectory in what follows.[4] Defining the real field components as $|\phi_i| \equiv \varphi/\sqrt{2}$ and $\beta = (\kappa_2 - 1)$, $\lambda = (\beta(\beta+1) + 1/2 + \kappa_1/12)$ and $\gamma = 2/(6)^{3n/2} \lesssim 0.14$, we obtain the potential during inflation [14]:

$$V \simeq \mu^4\left[1 - \frac{\beta}{2}\frac{\varphi^2}{M_{\rm Pl}^2} + \frac{\lambda}{4}\frac{\varphi^4}{M_{\rm Pl}^4} - \gamma\frac{\varphi^{3n}}{M^{3n}} + \cdots\right]. \tag{2.4}$$

In the following, we consider the situation where $|\gamma\frac{\varphi^{3n}}{M^{3n}}| \gg |\frac{\lambda}{4}\frac{\varphi^4}{M_{\rm Pl}^4}|$. Thus the quartic term $\varphi^4/M_{\rm Pl}^4$ can be neglected[5] and we find that the spectral index n_s, can be expressed in terms of the parameters of the potential and the number of e-folds N as[6]:

$$n_s \approx 1 - 2\beta\left[1 + \frac{(3n-1)(1-\beta)}{[(3n-2)\beta+1]e^{\beta(3n-2)N} + \beta - 1}\right] \quad \text{for } \beta \neq 0, \tag{2.5}$$

$$n_s \approx 1 - \frac{6n-2}{(3n-2)N + (3n-1)} \quad \text{for } \beta = 0. \tag{2.6}$$

The results are illustrated in Fig. 1. The predictions for n_s are close to the WMAP 5 year data [3] $n_s = 0.960 \pm 0.014$ for $n \geqslant 2$ and $\beta \lesssim 0.03$. In all cases we have taken $N = 60$.

The scale M, which governs the size of the flavon vev ϕ, and the inflation scale μ are determined by the temperature fluctuations $\delta T/T$ of the CMB (assuming that inflation and δT originate from ϕ) for a given generation scale M_* of the effective operator in Eq. (2.1). Specifically, we can relate the scale M_* to M and μ via the amplitude of the density perturbation when it re-enters the horizon,

$$\delta_H = \frac{1}{5\pi\sqrt{3}}\frac{V^{3/2}}{M_{\rm Pl}^3|V'|} = 1.91 \times 10^{-5}. \tag{2.7}$$

If we write this equation explicitly in terms of μ^2 and M and relate it to M_*, as defined below Eq. (2.1) we get:

$$M^{\frac{9n(n-1)}{3n-2}} = M_*^{3n-2} M_{\rm Pl}^{\frac{3n-4}{3n-2}} 5\pi\sqrt{3}\delta_H \times \left[\frac{\beta(1-\beta)}{3n\gamma[((3n-2)\beta+1)e^{(3n-2)N} + \beta - 1]}\right]^{\frac{1}{3n-2}} \times \left[\beta + \frac{\beta(1-\beta)}{((3n-2)\beta+1)e^{(3n-2)N} + \beta - 1}\right], \quad \text{for } \beta \neq 0, \tag{2.8}$$

$$M^{\frac{9n(n-1)}{3n-2}} = M_*^{3n-2} M_{\rm Pl}^{\frac{3n-4}{3n-2}} 5\pi\sqrt{3}\delta_H \times \left[\frac{1}{3n\gamma[(3n-2)N + 3n - 1]}\right]^{\frac{1}{3n-2}} \times \left[\frac{1}{(3n-2)N + 3n - 1}\right], \quad \text{for } \beta = 0. \tag{2.9}$$

With M_* around the GUT scale ($M_{\rm GUT} = 2 \times 10^{16}$ GeV), we obtain (again $N = 60$)

$$M \approx (10^{15}, 10^{16}) \text{ GeV}, \quad n = 2, 3, 4, \tag{2.10}$$

$$\mu \approx (10^{13}, 10^{14}) \text{ GeV}, \quad n = 2, 3, 4, \tag{2.11}$$

[4] When this is not the case, we have in general a multifield flavon inflationary scenario. This can arise in family symmetry models as considered for instance in [12], as part of a multistage inflationary model. A detailed analysis of this situation is left for a future publication.

[5] When $|\gamma\frac{\varphi^{3n}}{M^{3n}}| \ll |\frac{\lambda}{4}\frac{\varphi^4}{M_{\rm Pl}^4}|$ it turns out that $M \sim M_{\rm Pl}$, $\mu \sim 10^{15}$ GeV and so $M_*(> M) \sim M_{\rm Pl}$, which is not very useful information about the family symmetry breaking scale. Inflation can be obtained but it requires some fine tuning of the parameter λ [17].

[6] In standard slow roll inflation $n_s - 1 = 2\eta - 6\epsilon$, where η, ϵ are the standard slow roll parameters. In the present case we have $\epsilon \ll \eta$.

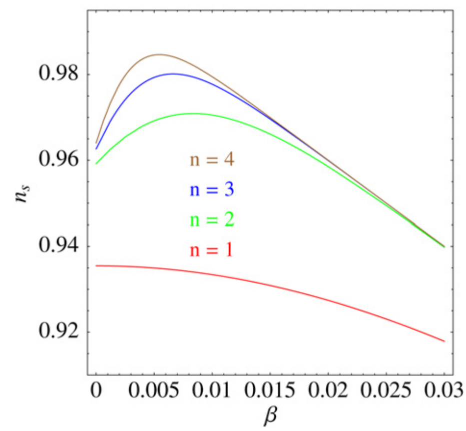

Fig. 1. Predictions for the spectral index n_s as a function of β for $N = 60$. For comparison, the results for the invariant combination of fields $(\bar{\phi}\phi)^n/M^{2n-2}$ for different n can be found in Fig. 1 of [11].

for all considered values of β. The numerical results are shown in Fig. 2. We note that the choice $M_* = M_{\rm GUT}$ is only an example. In principle M_* can be much lower and thus also M would be much lower (for example an intermediate scale $M_* \approx (10^{11}, 10^{13})$ GeV can give $M \approx (10^{11}, 10^{13})$ GeV, $\mu \approx (10^{10}, 10^{12})$ GeV).

For $n = 1$ and $N \sim 60$ (β in the relevant range), M_* is not longer a free parameter and in fact it is determined to be around 10^{24} GeV. In this case we are free to choose μ and thus we could in principle have low scale inflation under this condition. Also, in order to have $M < M_{\rm GUT}$, μ would have to be below about 10^{10}–10^{11} GeV. However, since M_* is found to be larger than the Planck scale, it cannot be regarded as a fundamental generation scale of the effective operator but itself has to emerge as an effective scale.

When (at least part of) the family symmetry breaking takes place below $M_{\rm GUT}$, this has interesting phenomenological consequences as we discuss in Section 3.

2.3. Example 2: Driving superfield(s) as inflaton

In supersymmetric theories the superpotentials which determine the flavons' vevs contain another class of fields in addition to the flavons, the so-called *driving superfields*. The driving superfields are singlets under the family symmetry, in contrast to the flavons.

As an example of how inflation may be realised from the driving superfields, we consider a vacuum alignment potential as studied in the SU(3) family symmetry model of [12]. We assume the situation that $\langle\phi_{23}\rangle \propto (0, 1, 1)^T$ and $\langle\Sigma\rangle = \mathrm{diag}(a, a, -2a)$ are already at their minima, and that the relevant part of the superpotential which governs the final step of family symmetry breaking is given by [12]

$$W = \kappa S(\bar{\phi}_{123}\phi_{123} - M^2) + \kappa' Y_{123}\bar{\phi}_{23}\phi_{123} + \kappa'' Z_{123}\bar{\phi}_{123}\Sigma\phi_{123} + \cdots. \tag{2.12}$$

S is the driving superfield for the flavon ϕ_{123}, i.e. the contribution to the scalar potential from $|F_S|^2$ governs the vev $\langle\phi_{123}\rangle$. In addition we assume a non-minimal Kähler potential of the form

$$K = |S|^2 + |\phi_{123}|^2 + |\bar{\phi}_{123}|^2 + |Y_{123}|^2 + |\bar{\phi}_{23}|^2 + |\phi_{23}|^2 + |Z_{123}|^2 + |\Sigma|^2 + \kappa_S\frac{|S|^4}{4M_{\rm Pl}^2} + \kappa_{SZ}\frac{|S|^2|Z_{123}|^2}{4M_{\rm Pl}^2} + \cdots. \tag{2.13}$$

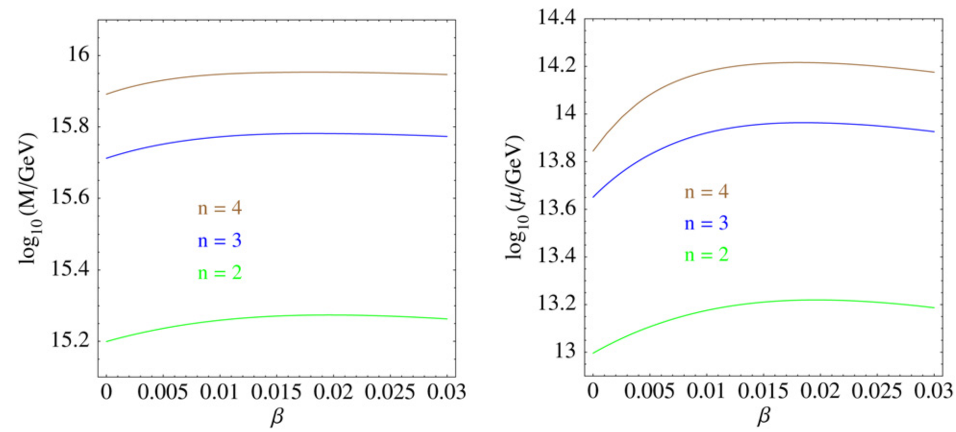

Fig. 2. Predictions for the family breaking scale M (left plot) and for the inflation scale μ (right plot) as a function of β for $N = 60$ and $M_* = M_{\rm GUT}$ ($M_{\rm GUT} = 2 \times 10^{16}$ GeV).

Although the theory is rather complicated we emphasise that this is taken from the existing family symmetry literature. For the purposes of inflation, we are interested in the epoch where the fields with larger vevs $Y_{123}, \phi_{123}, \bar{\phi}_{123}$ do not evolve, and inflation is provided by the fields with smaller vevs. We note that due to the vevs of ϕ_{23} and Σ, $SU(3)$ is already broken. In order to proceed, we analyse the supergravity scalar potential (2.3) focusing on the D-flat directions which are potentially promising for inflation. Setting $Y_{123} = \phi_{123} = \bar{\phi}_{123} = 0$ since the fields obtain large masses from the superpotential, the tree level scalar potential takes the simple form (expanded in powers of fields over $M_{\rm Pl}$)[7]

$$V = \kappa^2 M^4 \left[1 - \gamma \frac{\xi^2}{2M_{\rm Pl}^2} - 2\kappa_S \frac{\sigma^2}{2M_{\rm Pl}^2} + \cdots \right], \tag{2.14}$$

where we have defined $|S| = \sigma/\sqrt{2}$, $|Z_{123}| = \xi/\sqrt{2}$ and $\gamma = \kappa_{SZ} - 1$. From this expression, we see that if the two coefficients in front of the mass terms for σ and/or ξ are sufficiently small both/one of them can drive inflation.

If we assume that σ acts as the inflaton (choosing for instance $\gamma < -1/3$ such that the mass of ξ exceeds the Hubble scale) and taking into account loop corrections to the potential, it has been shown in [15,16] that for $\kappa_S \approx (0.005\text{–}0.01)$ and $\kappa \approx (0.001\text{–}0.05)$, a spectral index consistent with WMAP 5 year data [3], $n_s = 0.96 \pm 0.014$, is obtained. Finally, the scale M of family symmetry breaking along the $\langle \phi_{123} \rangle$-direction is determined from the temperature fluctuations $\delta T/T$ of the CMB to be

$$M \approx 10^{15}\ \text{GeV}, \tag{2.15}$$

about an order of magnitude below the GUT scale. After having analysed two example scenarios, let us now turn to a general qualitative discussion of possible consequences of flavon inflation.

3. Discussion and implications of flavon inflation

The connection between family symmetry breaking and inflation has several implications for theories of inflation as well as for theories of flavour. In this section we discuss some of the cosmological and particle physics consequences.

Many important implications are related to the fact that the scale of family symmetry breaking (which is connected to the scale of inflation) is determined by the temperature fluctuations of the CMB, i.e. inflation predicts the scale of family symmetry breaking. In the two examples presented in Sections 2.2 and 2.3, we have found that (at least the relevant part of the) family symmetry breaking takes place at about 10^{15} to 10^{16} GeV, that is, below the GUT scale. Another intriguing possibility would be flavon inflation at TeV energies, such that both, the flavour sector and the inflationary dynamics, might be observable at the LHC.

One attractive feature of having inflation after a possible GUT phase transition is that unwanted relics from the GUT phase transition, such as monopoles, are diluted. Furthermore, after spontaneous family symmetry breaking the symmetry is commonly completely broken, which means that, in particular, no continuous symmetry remains. Possibly created domain wall networks from remaining discrete symmetries are in general unproblematic, because they are effectively blown away by the pressure generated by higher-dimensional operators which break the discrete symmetries (cf. comment in footnote 2).

The fact that in some cases (as discussed in the text) inflation can predict the scale of family symmetry breaking to be below the GUT scale, can give rise to other additional consequences. For example, the renormalisation group (RG) evolution of the SM quantities from low energies to the GUT scale is modified by the new physics at intermediate energies. Thus, the predicted GUT scale ratios of Yukawa couplings from low energy data will be modified due to the intermediate family symmetry breaking scale, which would affect, for instance, the possibility of third family Yukawa unification. Furthermore, the predictions for the fermion masses and mixings emerge at the family symmetry breaking scale. The knowledge of this scale is important for precision tests of these predictions. In particular, the renormalisation group running between this scale and low energy has to be taken into account.

The idea of flavon inflation yields new possibilities for inflation model building, and in general predicts a rich variety of possible inflationary trajectories for single field and also multi-field inflation. In the example studied in Section 2.2 we found that if the flavon(s) in fundamental representations of an A_4 or Δ_{27} family symmetry act as the inflation(s), there are new invariant field combinations in the (super)potential which have not been considered for inflation model building so far. In the example in Section 2.3 we have seen that in addition to types of models similar to standard SUSY hybrid inflation, it is also generic (depending on the parameters of the Kähler potential) that the scalar components of more than one driving superfield participates in inflation. In addition, it is typical that family symmetry breaking proceeds in several steps, which would mean that before the observable inflation there could have been earlier stages of inflation.

Besides the rich structure of the potentials during inflation, there is also an interesting dynamics of the flavon fields after inflation. The potentials are usually such that not only the moduli of the vevs of the flavons are determined, but also that they point

[7] Here we show only the relevant terms for inflation. However one should keep in mind that quartic terms are present such that the field is evolving from large values to small ones. The details of this model have been presented in [16].

into specific directions in flavour space. When the flavons are moving towards their true values after inflation, the dynamics of the field evolution often has a much larger complexity and diversity than conventional inflation models. This is due to the fact that typically several flavon components are moving, and that the potentials have special shapes in order to force the flavon vevs to point in the desired directions in flavour space in the true minimum.

This can have consequences for the density perturbations (non-adiabaticities, non-Gaussianities, etc.) as well as for baryogenesis during preheating and during (and after) reheating. Non-thermal leptogenesis, for example, would be connected to the physics of family symmetry breaking and new possibilities for generating the baryon asymmetry will appear. Since flavons can play the role of either the inflaton or the waterfall fields, their decays into leptons will be determined by couplings which are associated with some particular flavour model. Thus successful non-thermal leptogenesis following flavon inflation can provide further constraints on flavon inflation models, leading to possible bounds on right-handed neutrino masses and so on. There could also be further constraints coming from the proton decay in the unified flavon inflation models. For instance, as the scale of family symmetry breaking M approaches the GUT scale M_{GUT}, the efficiency of monopole dilution is expected to fall. If, on the other hand, M is significantly below M_{GUT}, the monopoles will be inflated away, but the flavour messenger sector will affect gauge coupling unification, with implications for proton decay. It is also interesting to note that when global family symmetries break, there could be pseudo-Goldstone bosons appearing with interesting phenomenology.

4. Conclusion

In conclusion, we have shown that existing models based on a spontaneously broken family symmetry, proposed to resolve the flavour problem are naturally linked to cosmology. They introduce new and promising possibilities for cosmological inflation, which we have referred to generically as flavon inflation. In flavon inflation, the inflaton can be identified with either one of the flavon fields introduced to break the family symmetry, or with one of the driving fields used to align the flavon vevs. In either case the scales of inflation and family symmetry breaking result to be typically below the GUT scale in the presented examples. Since the family symmetry is broken completely (cf. comment in footnote 2) this provides a natural resolution of GUT scale cosmological relic problems, without introducing further relics. Moreover flavon inflation has a large number of interesting consequences for particle physics as well as for cosmology, which we have only briefly touched on here but which are worth exploring in more detail in future studies [17].

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