A new stage of fast inflation in the early universe and its signatures in the cosmic microwave background

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WMAP (Wilkinson Microwave Anisotropy Probe) confirms again the surprinsingly low quadrupole moments of the Cosmic Microwave Background fossil radiation (CMB) and suggests that they cannot be completely explained by galactic foreground contamination. The quadrupole and low multipoles correspond to the more primordial part of the spectrum. Till now, all tests of inflation with CMB, LSS (Large Scale Structure) and SN (supernovae) data refer to the so-called slow roll inflation (in which the kinetic energy of the field driving inflation is very small with respect to its potential energy). Recently, a team of theorists (Norma Sanchez and Hector de Vega, directors of research at CNRS, Paris Observatory/LERMA and UPMC/LPTHE respectively), together with Daniel Boyanovsky (professor at University of Pittsburgh/NSF) and Claudio Destri (professor at University of Milano-Biccoca/INFN) found a new generic stage of inflation: fast roll inflation, occurring earlier than the slow stage and merging smoothly with it. This fast roll stage dynamically modifies the primordial power spectrum accounting for the observed quadrupole suppression and leads to new oscillatory corrections on the low CMB multipoles. (Also, these new oscillations yield significant gains in likelihood). The fast roll stage fixes the initial inflation redshift to $0.915 \times 10^{56} \simeq e^{129}$. These results, combined with all available CMB+LSS+SN data, set up the following picture: A brief fast roll inflation stage is followed by a longer slow roll period, after which the universe enters in its radiation dominated era. The quadrupole modes exit the horizon during the fast stage and are suppressed as compared with the modes exiting the horizon later in the slow stage.

WMAP data give a strong support to the standard (concordance) model of the universe which explains today a wide set of cosmological and astronomical observations (cosmic microwave background (CMB) anisotropies, light elements abundances, large scale structure (LSS) and baryonic acoustic oscillations, Hubble constant, supernova luminosity/distance relations, and other measurements). In this model, the early stage of the universe is described by a short period of accelerated expansion in which the universe size expands at least a factor 10^{26} (inflation). Inflation is based on a scalar field (the inflaton) which drives the dynamics of the scale factor of the universe, plus small quantum fluctuations that seed large scale structure, CMB anisotropies, and primordial gravitational waves (see for instance the OP news of April 2008).

The polarization of the CMB radiation is composed by two modes: the "electric" part and the "magnetic" or primordial tensor part). Main CMB observables are the Temperature-Temperature correlations, the Temperature-polarization , and the polarization-polarization correlations. Angular correlations are translated into multipole decompositions of degree ℓ and amplitudes C_ℓ.

WMAP tested generic features of Inflation corresponding to the so-called slow-roll Inflation (in short, slow inflation) in which the inflaton kinetic energy is very small with respect to its potential energy, (thus, the inflaton rolls slowly and inflation evolution is approximated as a series of slow roll parameters).

Although there are no statistically significant departures from slow inflation at small angular scales (multipoles $\ell \gtrsim 100$), WMAP5 (2008) data confirm again the surprinsingly low quadrupoles ($\ell = 2$), and suggest that they cannot be completely explained by galactic foreground contamination. (The low value of the CMB quadrupole has been an intriguing feature on large angular scales since first observed by COBE/DMR in 1992, and confirmed by WMAP3 and WMAP5).

The relevance of the observed quadrupole suppression in the standard model with slow inflation can be assesed by determining in the best fit of this model the probability to find the quadrupole as low or lower its observed value. This probability turns out to be only 0.031. Thus, in the standard model with slow-roll inflation, the observed quadrupole realizes a rather unlikely event which has only a 3% probability. This supports the necessity for a cosmological explanation of the quadrupole depression beyond the standard model and slow-roll inflation.

In this context, the new results of the team are as follows:

- A new generic inflation regime is found from the exact non linear evolution of inflation: this is a brief **fast roll stage** (in short, fast inflation) in which the inflaton kinetic energy is of the order (or larger) than its potential energy, (thus the inflaton rolls fast). This fast stage **preceds** the slow regime and mergers smoothly with it. During fast roll, the inflaton evolves rapidly during a short period, and then slows down by the cosmological expansion settling in the slow roll stage.

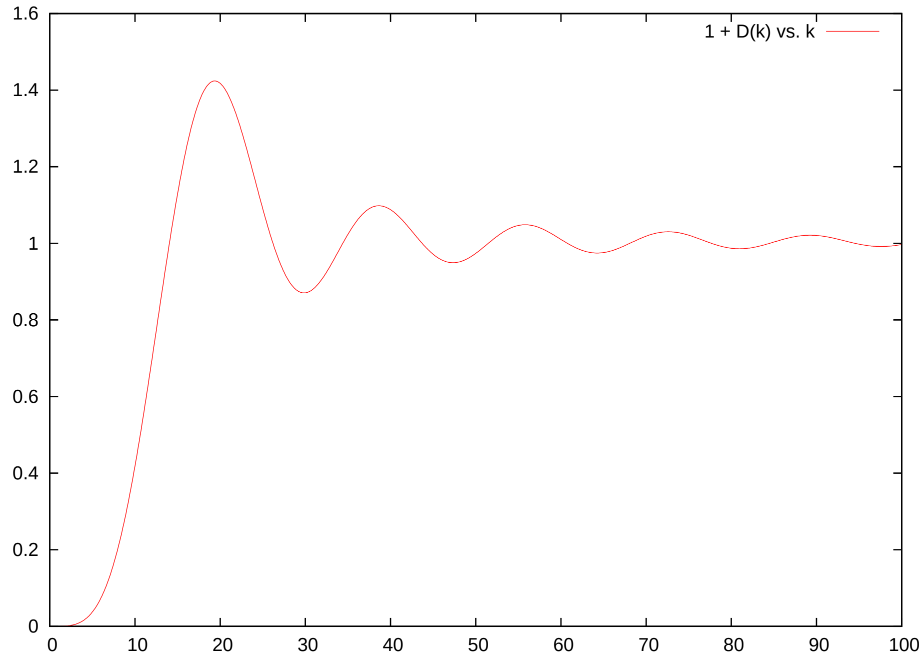

FIG. 1: The transfer function $D(k)$ due to the new fast-roll stage found by the team . $[1 + D(k)$ is plotted vs. the wavenumber $k]$. The first peak is clearly its dominant feature. This peak corresponds to modes which are today horizon size and affect the lowest CMB multipoles. $D(k)$ oscillates around zero and therefore produces **suppressions as well as enhancements** in the primordial power spectrum, in particular the quadrupole gets suppressed. The transfert function vanishes asymptotically for large wavenumbers (reaching the known slow roll period).

- The fast roll stage leads to a purely attractive potential in the evolution of the primordial fluctuations, (while slow-roll inflation leads to a repulsive potential). The attractive character of the potential felt by the fluctuations during the fast-roll stage leads to a **suppression** of the quadrupole moment for the temperature and polarization spectra. The fast-roll stage modifies the primordial power spectrum by a transfer function (Fig.1). Its oscillatory form at long wavelengths, leads also to new superimposed **oscillatory corrections** on the low CMB multipoles. (Also, these fast roll oscillations yield significant better gains in likelihood than purely slow roll, or than

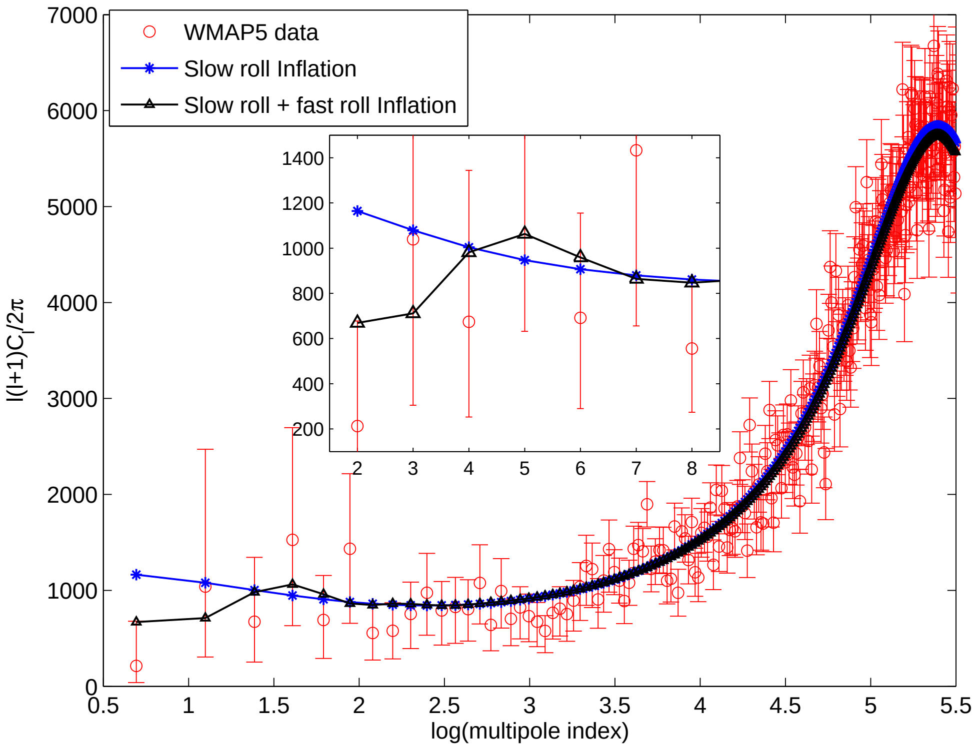

FIG. 2: Comparison with the experimental WMAP5 data of the theoretical temperature multipoles computed in the best fit point of the two models (with and without the fast-roll stage) using the WMAP5+SN+SDSS data. They are plotted as functions of the natural logarithm of the multipole degree ℓ. The insert contains an enlargement in linear scale of the first seven multipoles. (The error bars in the plotted range of ℓ are mostly due to cosmic variance. Error bars of the WMAP5 data are one-sigma (68%c.l.).)

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The observation of the low CMB quadrupole sparked many different proposals for their explanation. The **fast-roll** explanation of the quadrupole does not require to introduce ad hoc hypothesis neither modifications to the standard model. The new feature emerges from the dynamics: a brief but consequential stage of fast-roll inflation occurs earlier than the known slow-roll period. Thus, the quadrupole mode exits the horizon during the fast-roll stage **before** slow-roll begins and gets **suppressed** as compared with the modes exiting the horizon later during the slow roll stage.

- A new Monte Carlo Markov Chains (MCMC) analysis of all available CMB and LSS data (WMAP5, Sloan (SDSS) and Supernovae (SN) data) have been performed by

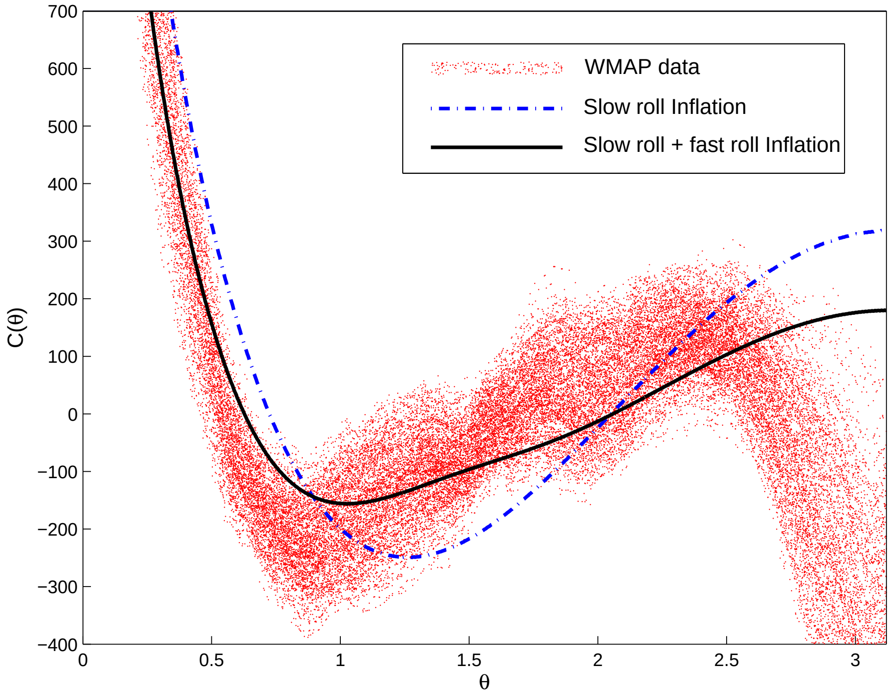

FIG. 3: The angular distance two point temperature correlation function for the two models (with and without the fast-roll stage) vs. the angle θ. The two correlators differ from each other only for large angles $\theta \gtrsim 1$ corresponding to the lowest multipoles ℓ . All ℓ-modes except the lowest ones are practically identical in the two cases. Also shown are the WMAP data, (the truly observed correlator runs approximately in the middle of the red band, the width of the data band is mostly due to the cosmic variance). Fast-roll + slow roll inflation reproduces the two point correlator better than pure slow-roll inflation.

the team by including fast-roll inflation with the result: The quadrupole mode, equal to 0.238 Gpc^{-1}, exits the horizon **during** the fast-roll stage just earlier than the transition to slow-roll (this transition corresponds to 0.290 Gpc^{-1}). Fast-roll inflation provides a better fit than slow-roll inflation for **all** the multipoles and for the angular correlators. (Figs 2,3 illustrate the temperature multipoles and corresponding angular correlator, the obtained plots for the other multipole correlators yield similar conclusions). Besides reproducing the quadrupole depression, the fast roll fit accounts for the oscillations of the lower multipole data. The best fit values of the other cosmological parameters are the same as compared to slow-roll inflation.

- The fast-roll stage **fixes** the initial inflation redshift to be $0.915 \times 10^{56} \simeq e^{129}$. The picture of the universe explaining the quadrupole suppression from the theory of inflation combined with analysis of CMB+LSS+SN data is the following: A brief fast roll inflation stage is followed by a longuer slow roll inflation period after which the universe enters in its radiation dominated era. The quadrupole modes exit the horizon during the fast stage (just **before** soll-roll begins) and are therefore **suppressed** as compared with the modes exiting the horizon later in the slow-roll stage.

Finally, initial fast-roll conditions have been recently generalized by the team to the quantum level [ref 2]: namely, a more excited transitory fast-roll stage appears which becomes in its evolution the classical fast-roll one. Such transitory stage imprints its own corrections to the power spectra, expected to allow further fit improvement to the lower (and more primordial) CMB multipoles. These new quantum fast-roll effects provide a predictive model to be contrasted to the forthcoming and future CMB data.

References

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[**2**] F. Cao, H. J. de Vega, N. Sanchez "Quantum slow-roll and quantum fast-roll inflationary initial conditions: CMB quadrupole suppression and further effects on the low CMB multipoles" Phys. Rev. **D 78**, 083508 (2008)

Further reading:

[**3**] D. Boyanovsky, H. J. de Vega, N. G. Sanchez, "CMB quadrupole suppression: I. Initial conditions of inflationary perturbations " Phys.Rev. **D 74**, 123006 (2006)

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