On multifield inflation, adiabaticity, and the speed of sound of the curvature perturbations

Atal, V.

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Author: Atal, Vicente
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Bibliography

[1] E. Hubble, "A relation between distance and radial velocity among extra-galactic nebulae," *PNAS*, vol. 15, p. 169, 1929.

[2] G. Lemaître, "Un univers homogène de masse constante et de rayon croissant, rendant compte de la vitesse radiale des nébuleuses extra-galactiques," *Ann.Soc.Sci.Bruxelles*, vol. A 47, p. 49, 1927.

[3] J.-P. Luminet, "Lemaître's Big Bang," *1503.08304*, 2014.

[4] E. W. Kolb and M. S. Turner, *The Early Universe*. Addison-Wesley, 1990. Frontiers in Physics, 69.

[5] A. R. B. H. and G. G.., "The Origin of Chemical Elements," *Phys.Rev*, vol. 73, p. 803, 1948.

[6] R. Alpher and H. R, "On the Relative Abundance of the Elements," *Nature*, vol. 162, pp. 774–775, 1949.

[7] A. A. Penzias and R. W. Wilson, "A Measurement of excess antenna temperature at 4080-Mc/s," *Astrophys. J.*, vol. 142, pp. 419–421, 1965.

[8] R. H. Dicke, P. J. E. Peebles, P. G. Roll, and D. T. Wilkinson, "Cosmic Black-Body Radiation," *Astrophys. J.*, vol. 142, pp. 414–419, 1965.

[9] J. C. Mather *et al.*, "Measurement of the Cosmic Microwave Background spectrum by the COBE FIRAS instrument," *Astrophys. J.*, vol. 420, pp. 439–444, 1994.

[10] G. F. Smoot *et al.*, "Structure in the COBE differential microwave radiometer first year maps," *Astrophys. J.*, vol. 396, pp. L1–L5, 1992.

[11] R. Adam *et al.*, "Planck 2015 results. I. Overview of products and scientific results," 2015.

[12] P. A. R. Ade *et al.*, "Planck 2015 results. XIII. Cosmological parameters," 2015.

[13] A. H. Guth, "The Inflationary Universe: A Possible Solution to the Horizon and Flatness Problems," *Phys.Rev.*, vol. D23, pp. 347–356, 1981.

[14] A. A. Starobinsky, "Relict Gravitation Radiation Spectrum and Initial State of the Universe. (In Russian)," *JETP Lett.*, vol. 30, pp. 682–685, 1979.

[15] K. Sato, "First Order Phase Transition of a Vacuum and Expansion of the Universe," *Mon.Not.Roy.Astron.Soc.*, vol. 195, pp. 467–479, 1981.

[16] A. D. Linde, "A New Inflationary Universe Scenario: A Possible Solution of the Horizon, Flatness, Homogeneity, Isotropy and Primordial Monopole Problems," *Phys.Lett.*, vol. B108, pp. 389–393, 1982.

[17] A. Albrecht and P. J. Steinhardt, "Cosmology for Grand Unified Theories with Radiatively Induced Symmetry Breaking," *Phys.Rev.Lett.*, vol. 48, pp. 1220–1223, 1982.

[18] A. H. Guth and E. J. Weinberg, "Could the universe have recovered from a slow first-order phase transition?," *Nuclear Physics B*, vol. 212, no. 2, pp. 321 – 364, 1983.

[19] V. F. Mukhanov and G. V. Chibisov, "Quantum Fluctuation and Nonsingular Universe. (In Russian)," *JETP Lett.*, vol. 33, pp. 532–535, 1981.

[20] A. Riotto, "Inflation and the theory of cosmological perturbations," in *Astroparticle physics and cosmology. Proceedings: Summer School, Trieste, Italy, Jun 17-Jul 5 2002*, pp. 317–413, 2002.

[21] M. Sasaki, "Large Scale Quantum Fluctuations in the Inflationary Universe," *Prog. Theor. Phys.*, vol. 76, p. 1036, 1986.

[22] V. F. Mukhanov, "Quantum Theory of Gauge Invariant Cosmological Perturbations," *Sov. Phys. JETP*, vol. 67, pp. 1297–1302, 1988. [Zh. Eksp. Teor. Fiz.94N7,1(1988)].

[23] T. S. Bunch and P. C. W. Davies, "Quantum Field Theory in de Sitter Space: Renormalization by Point Splitting," *Proc. Roy. Soc. Lond.*, vol. A360, pp. 117–134, 1978.

[24] S. Weinberg, "Adiabatic modes in cosmology," *Phys. Rev.*, vol. D67, p. 123504, 2003.

[25] J. Garriga and V. F. Mukhanov, "Perturbations in k-inflation," *Phys.Lett.*, vol. B458, pp. 219–225, 1999.

[26] D. Baumann, D. Green, and R. A. Porto, "B-modes and the Nature of Inflation," *JCAP*, vol. 1501, no. 01, p. 016, 2015.

[27] G. A. Palma and A. Soto, "B-modes and the sound speed of primordial fluctuations," 2014.

[28] A. Lewis, A. Challinor, and A. Lasenby, "Efficient computation of CMB anisotropies in closed FRW models," *Astrophys.J.*, vol. 538, pp. 473–476, 2000.

[29] J. Lesgourgues, "The Cosmic Linear Anisotropy Solving System (CLASS) I: Overview," 2011.

[30] P. A. R. Ade *et al.*, "Planck 2015 results. XX. Constraints on inflation," 2015.

[31] A. D. Linde, "Chaotic Inflation," *Phys.Lett.*, vol. B129, pp. 177–181, 1983.

[32] K. Freese, J. A. Frieman, and A. V. Olinto, "Natural inflation with pseudo - Nambu-Goldstone bosons," *Phys.Rev.Lett.*, vol. 65, pp. 3233–3236, 1990.

[33] P. A. R. Ade *et al.*, "BICEP2 / Keck Array VI: Improved Constraints On Cosmology and Foregrounds When Adding 95 GHz Data From Keck Array," 2015.

[34] C. Cheung, P. Creminelli, A. L. Fitzpatrick, J. Kaplan, and L. Senatore, "The Effective Field Theory of Inflation," *JHEP*, vol. 0803, p. 014, 2008.

[35] A. P. S. Yadav and B. D. Wandelt, "Primordial Non-Gaussianity in the Cosmic Microwave Background," *Advances in Astronomy*, vol. 2010, p. 71, 2010.

[36] V. Acquaviva, N. Bartolo, S. Matarrese, and A. Riotto, "Second order cosmological perturbations from inflation," *Nucl.Phys.*, vol. B667, pp. 119–148, 2003.

[37] J. M. Maldacena, "Non-Gaussian features of primordial fluctuations in single field inflationary models," *JHEP*, vol. 0305, p. 013, 2003.

[38] L. Senatore, K. M. Smith, and M. Zaldarriaga, "Non-Gaussianities in Single Field Inflation and their Optimal Limits from the WMAP 5-year Data," *JCAP*, vol. 1001, p. 028, 2010.

[39] E. Komatsu and D. N. Spergel, "Acoustic signatures in the primary microwave background bispectrum," *Phys. Rev.*, vol. D63, p. 063002, 2001.

[40] P. A. R. Ade *et al.*, "Planck 2015 results. XVII. Constraints on primordial non-Gaussianity," 2015.

[41] D. Baumann, D. Green, H. Lee, and R. A. Porto, "Signs of Analyticity in Single-Field Inflation," 2015.

[42] E. Silverstein and D. Tong, "Scalar speed limits and cosmology: Acceleration from D-cceleration," *Phys. Rev.*, vol. D70, p. 103505, 2004.

[43] M. Alishahiha, E. Silverstein, and D. Tong, "DBI in the sky," *Phys. Rev.*, vol. D70, p. 123505, 2004.

[44] A. A. Starobinsky, "Spectrum of adiabatic perturbations in the universe when there are singularities in the inflation potential," *JETP Lett.*, vol. 55, pp. 489–494, 1992.

[45] D. Polarski and A. A. Starobinsky, "Spectra of perturbations produced by double inflation with an intermediate matter dominated stage," *Nucl. Phys.*, vol. B385, pp. 623–650, 1992.

[46] D. J. H. Chung, E. W. Kolb, A. Riotto, and I. I. Tkachev, "Probing Planckian physics: Resonant production of particles during inflation and features in the primordial power spectrum," *Phys. Rev.*, vol. D62, p. 043508, 2000.

[47] J. A. Adams, B. Cresswell, and R. Easther, "Inflationary perturbations from a potential with a step," *Phys.Rev.*, vol. D64, p. 123514, 2001.

[48] J.-O. Gong, "Breaking scale invariance from a singular inflaton potential," *JCAP*, vol. 0507, p. 015, 2005.

[49] A. Ashoorioon and A. Krause, "Power Spectrum and Signatures for Cascade Inflation," 2006.

[50] A. E. Romano and M. Sasaki, "Effects of particle production during inflation," *Phys. Rev.*, vol. D78, p. 103522, 2008.

[51] A. Ashoorioon, A. Krause, and K. Turzynski, "Energy Transfer in Multi Field Inflation and Cosmological Perturbations," *JCAP*, vol. 0902, p. 014, 2009.

[52] S. H. H. Tye, J. Xu, and Y. Zhang, "Multi-field Inflation with a Random Potential," *JCAP*, vol. 0904, p. 018, 2009.

[53] S. H. H. Tye and J. Xu, "A Meandering Inflaton," *Phys. Lett.*, vol. B683, pp. 326–330, 2010.

[54] N. Barnaby, "On Features and Nongaussianity from Inflationary Particle Production," *Phys. Rev.*, vol. D82, p. 106009, 2010.

[55] A. Achúcarro, J.-O. Gong, S. Hardeman, G. A. Palma, and S. P. Patil, "Features of heavy physics in the CMB power spectrum," *JCAP*, vol. 1101, p. 030, 2011.

[56] X. Chen, "Primordial Features as Evidence for Inflation," *JCAP*, vol. 1201, p. 038, 2012.

[57] A. D. Linde and V. F. Mukhanov, "Nongaussian isocurvature perturbations from inflation," *Phys. Rev.*, vol. D56, pp. 535–539, 1997.

[58] N. Bartolo, S. Matarrese, and A. Riotto, "Nongaussianity from inflation," *Phys. Rev.*, vol. D65, p. 103505, 2002.

[59] F. Bernardeau and J.-P. Uzan, "NonGaussianity in multifield inflation," *Phys. Rev.*, vol. D66, p. 103506, 2002.

[60] D. H. Lyth, C. Ungarelli, and D. Wands, "The Primordial density perturbation in the curvaton scenario," *Phys. Rev.*, vol. D67, p. 023503, 2003.

[61] N. Bartolo, E. Komatsu, S. Matarrese, and A. Riotto, "Non-Gaussianity from inflation: Theory and observations," *Phys. Rept.*, vol. 402, pp. 103–266, 2004.

[62] X. Chen, M.-x. Huang, S. Kachru, and G. Shiu, "Observational signatures and non-Gaussianities of general single field inflation," *JCAP*, vol. 0701, p. 002, 2007.

[63] A. D. Linde, "Generation of Isothermal Density Perturbations in the Inflationary Universe," *Phys. Lett.*, vol. B158, pp. 375–380, 1985.

[64] A. A. Starobinsky, "Multicomponent de Sitter (Inflationary) Stages and the Generation of Perturbations," *JETP Lett.*, vol. 42, pp. 152–155, 1985. [Pisma Zh. Eksp. Teor. Fiz.42,124(1985)].

[65] D. Polarski and A. A. Starobinsky, "Isocurvature perturbations in multiple inflationary models," *Phys. Rev.*, vol. D50, pp. 6123–6129, 1994.

[66] C. Gordon, D. Wands, B. A. Bassett, and R. Maartens, "Adiabatic and entropy perturbations from inflation," *Phys.Rev.*, vol. D63, p. 023506, 2001.

[67] S. Groot Nibbelink and B. J. W. van Tent, "Density perturbations arising from multiple field slow roll inflation," 2000.

[68] S. Groot Nibbelink and B. van Tent, "Scalar perturbations during multiple field slow-roll inflation," *Class.Quant.Grav.*, vol. 19, pp. 613–640, 2002.

[69] F. Di Marco, F. Finelli, and R. Brandenberger, "Adiabatic and isocurvature perturbations for multifield generalized Einstein models," *Phys. Rev.*, vol. D67, p. 063512, 2003.

[70] Z. Lalak, D. Langlois, S. Pokorski, and K. Turzynski, "Curvature and isocurvature perturbations in two-field inflation," *JCAP*, vol. 0707, p. 014, 2007.

[71] K.-Y. Choi, J.-O. Gong, and D. Jeong, "Evolution of the curvature perturbation during and after multi-field inflation," *JCAP*, vol. 0902, p. 032, 2009.

[72] C. P. Burgess, "Introduction to Effective Field Theory," *Ann. Rev. Nucl. Part. Sci.*, vol. 57, pp. 329–362, 2007.

[73] A. J. Tolley and M. Wyman, "The Gelaton Scenario: Equilateral non-Gaussianity from multi-field dynamics," *Phys.Rev.*, vol. D81, p. 043502, 2010.

[74] X. Chen and Y. Wang, "Large non-Gaussianities with Intermediate Shapes from Quasi-Single Field Inflation," *Phys.Rev.*, vol. D81, p. 063511, 2010.

[75] X. Chen and Y. Wang, "Quasi-Single Field Inflation and Non-Gaussianities," *JCAP*, vol. 1004, p. 027, 2010.

[76] A. Achúcarro, J.-O. Gong, S. Hardeman, G. A. Palma, and S. P. Patil, "Mass hierarchies and non-decoupling in multi-scalar field dynamics," *Phys.Rev.*, vol. D84, p. 043502, 2011.

[77] S. Cremonini, Z. Lalak, and K. Turzynski, "On Non-Canonical Kinetic Terms and the Tilt of the Power Spectrum," *Phys. Rev.*, vol. D82, p. 047301, 2010.

[78] S. Cremonini, Z. Lalak, and K. Turzynski, "Strongly Coupled Perturbations in Two-Field Inflationary Models," *JCAP*, vol. 1103, p. 016, 2011.

[79] D. Baumann and D. Green, "Equilateral Non-Gaussianity and New Physics on the Horizon," *JCAP*, vol. 1109, p. 014, 2011.

[80] G. Shiu and J. Xu, "Effective Field Theory and Decoupling in Multi-field Inflation: An Illustrative Case Study," *Phys.Rev.*, vol. D84, p. 103509, 2011.

[81] A. Achúcarro, J.-O. Gong, S. Hardeman, G. A. Palma, and S. P. Patil, "Effective theories of single field inflation when heavy fields matter," *JHEP*, vol. 1205, p. 066, 2012.

[82] X. Gao, D. Langlois, and S. Mizuno, "Influence of heavy modes on perturbations in multiple field inflation," *JCAP*, vol. 1210, p. 040, 2012.

[83] S. Cespedes and G. A. Palma, "Cosmic inflation in a landscape of heavy-fields," *JCAP*, vol. 1310, p. 051, 2013.

[84] W. Hu and M. J. White, "Acoustic signatures in the cosmic microwave background," *Astrophys. J.*, vol. 471, pp. 30–51, 1996.

[85] J. Meyers and N. Sivanandam, "Non-Gaussianities in Multifield Inflation: Superhorizon Evolution, Adiabaticity, and the Fate of fnl," *Phys. Rev.*, vol. D83, p. 103517, 2011.

[86] S. Renaux-Petel and K. Turzynski, "On reaching the adiabatic limit in multi-field inflation," *JCAP*, vol. 1506, no. 06, p. 010, 2015.

[87] J. Ellis, M. A. G. Garcia, D. V. Nanopoulos, and K. A. Olive, "Two-Field Analysis of No-Scale Supergravity Inflation," *JCAP*, vol. 1501, no. 01, p. 010, 2015.

[88] S. Bielleman, L. E. Ibanez, F. G. Pedro, and I. Valenzuela, "Multifield Dynamics in Higgs-Otic Inflation," 2015.

[89] S. Weinberg, "Must cosmological perturbations remain non-adiabatic after multi-field inflation?," *Phys. Rev.*, vol. D70, p. 083522, 2004.

[90] G. A. Palma, "Untangling features in the primordial spectra," *JCAP*, vol. 1504, no. 04, p. 035, 2015.

[91] S. Mooij, G. A. Palma, G. Panotopoulos, and A. Soto, "Consistency relations for sharp features in the primordial spectra," *JCAP*, vol. 1510, no. 10, p. 062, 2015.

[92] S. Cespedes, V. Atal, and G. A. Palma, "On the importance of heavy fields during inflation," *JCAP*, vol. 1205, p. 008, 2012.

[93] A. Avgoustidis, S. Cremonini, A.-C. Davis, R. H. Ribeiro, K. Turzynski, *et al.*, "Decoupling Survives Inflation: A Critical Look at Effective Field Theory Violations During Inflation," *JCAP*, vol. 1206, p. 025, 2012.

[94] R. Gwyn, G. A. Palma, M. Sakellariadou, and S. Sypsas, "Effective field theory of weakly coupled inflationary models," *JCAP*, vol. 1304, p. 004, 2013.

[95] X. Chen and Y. Wang, "Quasi-Single Field Inflation with Large Mass," *JCAP*, vol. 1209, p. 021, 2012.

[96] E. Komatsu *et al.*, "Seven-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Cosmological Interpretation," *Astrophys. J. Suppl.*, vol. 192, p. 18, 2011.

[97] D. Cannone, N. Bartolo, and S. Matarrese, "Perturbative Unitarity of Inflationary Models with Features," 2014.

[98] P. Adshead and W. Hu, "Bounds on non-adiabatic evolution in single-field inflation," 2014.

[99] G. German, G. G. Ross, and S. Sarkar, "Low scale inflation," *Nucl. Phys.*, vol. B608, pp. 423–450, 2001.

[100] R. Allahverdi, K. Enqvist, J. Garcia-Bellido, and A. Mazumdar, "Gauge invariant MSSM inflaton," *Phys. Rev. Lett.*, vol. 97, p. 191304, 2006.

[101] A. Achúcarro, V. Atal, S. Céspedes, J.-O. Gong, G. A. Palma, *et al.*, "Heavy fields, reduced speeds of sound and decoupling during inflation," *Phys.Rev.*, vol. D86, p. 121301, 2012.

[102] C. Burgess, M. Horbatsch, and S. Patil, "Inflating in a Trough: Single-Field Effective Theory from Multiple-Field Curved Valleys," *JHEP*, vol. 1301, p. 133, 2013.

[103] E. Castillo, B. Koch, and G. Palma, "On the integration of fields and quanta in time dependent backgrounds," 2013.

[104] C. Burgess, J. M. Cline, and R. Holman, "Effective field theories and inflation," *JCAP*, vol. 0310, p. 004, 2003.

[105] S. Weinberg, "Effective Field Theory for Inflation," *Phys.Rev.*, vol. D77, p. 123541, 2008.

[106] S. Pi and M. Sasaki, "Curvature Perturbation Spectrum in Two-field Inflation with a Turning Trajectory," *JCAP*, vol. 1210, p. 051, 2012.

[107] W. Hu, "Generalized Slow Roll for Non-Canonical Kinetic Terms," *Phys.Rev.*, vol. D84, p. 027303, 2011.

[108] A. Achúcarro, J.-O. Gong, G. A. Palma, and S. P. Patil, "Correlating features in the primordial spectra," *Phys.Rev.*, vol. D87, p. 121301, 2013.

[109] M. Park and L. Sorbo, "Sudden variations in the speed of sound during inflation: features in the power spectrum and bispectrum," *Phys.Rev.*, vol. D85, p. 083520, 2012.

[110] V. Miranda, W. Hu, and P. Adshead, "Warp Features in DBI Inflation," *Phys.Rev.*, vol. D86, p. 063529, 2012.

[111] M. Nakashima, R. Saito, Y.-i. Takamizu, and J. Yokoyama, "The effect of varying sound velocity on primordial curvature perturbations," *Prog.Theor.Phys.*, vol. 125, pp. 1035–1052, 2011.

[112] R. Bean, X. Chen, G. Hailu, S.-H. H. Tye, and J. Xu, "Duality Cascade in Brane Inflation," *JCAP*, vol. 0803, p. 026, 2008.

[113] N. Bartolo, D. Cannone, and S. Matarrese, "The Effective Field Theory of Inflation Models with Sharp Features," *JCAP*, vol. 1310, p. 038, 2013.

[114] P. Adshead, W. Hu, and V. Miranda, "Bispectrum in Single-Field Inflation Beyond Slow-Roll," *Phys.Rev.*, vol. D88, p. 023507, 2013.

[115] R. H. Ribeiro, "Inflationary signatures of single-field models beyond slow-roll," *JCAP*, vol. 1205, p. 037, 2012.

[116] Y.-F. Cai and H.-Y. Xia, "Inflation with multiple sound speeds: a model of multiple DBI type actions and non-Gaussianities," *Phys.Lett.*, vol. B677, pp. 226–234, 2009.

[117] R. Saito and Y.-i. Takamizu, "Localized Features in Non-Gaussianity from Heavy Physics," *JCAP*, vol. 1306, p. 031, 2013.

[118] Y.-F. Cai, W. Zhao, and Y. Zhang, "CMB Power Asymmetry from Primordial Sound Speed Parameter," *Phys.Rev.*, vol. D89, p. 023005, 2014.

[119] J.-O. Gong, K. Schalm, and G. Shiu, "Correlating correlation functions of primordial perturbations," 2014.

[120] L.-M. Wang and M. Kamionkowski, "The Cosmic microwave background bispectrum and inflation," *Phys.Rev.*, vol. D61, p. 063504, 2000.

[121] X. Chen, R. Easther, and E. A. Lim, "Generation and Characterization of Large Non-Gaussianities in Single Field Inflation," *JCAP*, vol. 0804, p. 010, 2008.

[122] F. Arroja, A. E. Romano, and M. Sasaki, "Large and strong scale dependent bispectrum in single field inflation from a sharp feature in the mass," *Phys.Rev.*, vol. D84, p. 123503, 2011.

[123] J. Martin and L. Sriramkumar, "The scalar bi-spectrum in the Starobinsky model: The equilateral case," *JCAP*, vol. 1201, p. 008, 2012.

[124] P. Adshead, C. Dvorkin, W. Hu, and E. A. Lim, "Non-Gaussianity from Step Features in the Inflationary Potential," *Phys.Rev.*, vol. D85, p. 023531, 2012.

[125] F. Arroja and M. Sasaki, "Strong scale dependent bispectrum in the Starobinsky model of inflation," *JCAP*, vol. 1208, p. 012, 2012.

[126] Y.-i. Takamizu, S. Mukohyama, M. Sasaki, and Y. Tanaka, "Non-Gaussianity of superhorizon curvature perturbations beyond δ N formalism," *JCAP*, vol. 1006, p. 019, 2010.

[127] U. H. Danielsson, "A Note on inflation and transPlanckian physics," *Phys.Rev.*, vol. D66, p. 023511, 2002.

[128] B. R. Greene, K. Schalm, G. Shiu, and J. P. van der Schaar, "Decoupling in an expanding universe: Backreaction barely constrains short distance effects in the CMB," *JCAP*, vol. 0502, p. 001, 2005.

[129] P. D. Meerburg, J. P. van der Schaar, and P. S. Corasaniti, "Signatures of Initial State Modifications on Bispectrum Statistics," *JCAP*, vol. 0905, p. 018, 2009.

[130] M. G. Jackson and K. Schalm, "Model Independent Signatures of New Physics in the Inflationary Power Spectrum," *Phys.Rev.Lett.*, vol. 108, p. 111301, 2012.

[131] X. Gao, D. Langlois, and S. Mizuno, "Oscillatory features in the curvature power spectrum after a sudden turn of the inflationary trajectory," *JCAP*, vol. 10, p. 23, 2013.

[132] T. Noumi and M. Yamaguchi, "Primordial spectra from sudden turning trajectory," 2013.

[133] L. Covi, J. Hamann, A. Melchiorri, A. Slosar, and I. Sorbera, "Inflation and WMAP three year data: Features have a Future!," *Phys.Rev.*, vol. D74, p. 083509, 2006.

[134] M. Benetti, M. Lattanzi, E. Calabrese, and A. Melchiorri, "Features in the primordial spectrum: new constraints from WMAP7+ACT data and prospects for Planck," *Phys.Rev.*, vol. D84, p. 063509, 2011.

[135] P. Adshead and W. Hu, "Fast Computation of First-Order Feature-Bispectrum Corrections," *Phys.Rev.*, vol. D85, p. 103531, 2012.

[136] M. Benetti, "Updating constraints on inflationary features in the primordial power spectrum with the Planck data," *Phys.Rev.*, vol. D88, p. 087302, Oct. 2013.

[137] J. Hamann, L. Covi, A. Melchiorri, and A. Slosar, "New Constraints on Oscillations in the Primordial Spectrum of Inflationary Perturbations," *Phys.Rev.*, vol. D76, p. 023503, 2007.

[138] M. Benetti, S. Pandolfi, M. Lattanzi, M. Martinelli, and A. Melchiorri, "Featuring the primordial power spectrum: new constraints on interrupted slow-roll from CMB and LRG data," *Phys.Rev.*, vol. D87, p. 023519, 2013.

[139] J. Martin and C. Ringeval, "Superimposed oscillations in the WMAP data?," *Phys.Rev.*, vol. D69, p. 083515, 2004.

[140] R. Flauger, L. McAllister, E. Pajer, A. Westphal, and G. Xu, "Oscillations in the CMB from Axion Monodromy Inflation," *JCAP*, vol. 1006, p. 009, 2010.

[141] M. Aich, D. K. Hazra, L. Sriramkumar, and T. Souradeep, "Oscillations in the inflaton potential: Complete numerical treatment and comparison with the recent and forthcoming CMB datasets," *Phys.Rev.*, vol. D87, p. 083526, 2013.

[142] P. D. Meerburg, R. A. M. J. Wijers, and J. P. van der Schaar, "WMAP7 constraints on oscillations in the primordial power spectrum," *MNRS*, vol. 421, pp. 369–380, Mar. 2012.

[143] H. Peiris, R. Easther, and R. Flauger, "Constraining Monodromy Inflation," *JCAP*, vol. 1309, p. 018, 2013.

[144] P. D. Meerburg, D. N. Spergel, and B. D. Wandelt, "Searching for Oscillations in the Primordial Power Spectrum: Perturbative Approach (Paper I)," 2013.

[145] P. D. Meerburg and D. N. Spergel, "Searching for Oscillations in the Primordial Power Spectrum: Constraints from Planck (Paper II)," 2013.

[146] P. Ade *et al.*, "Planck 2013 results. XXII. Constraints on inflation," 2013.

[147] V. Miranda and W. Hu, "Inflationary Steps in the Planck Data," 2013.

[148] E. D. Stewart, "The Spectrum of density perturbations produced during inflation to leading order in a general slow roll approximation," *Phys.Rev.*, vol. D65, p. 103508, 2002.

[149] J.-O. Gong and E. D. Stewart, "The Density perturbation power spectrum to second order corrections in the slow roll expansion," *Phys.Lett.*, vol. B510, pp. 1–9, 2001.

[150] J. Choe, J.-O. Gong, and E. D. Stewart, "Second order general slow-roll power spectrum," *JCAP*, vol. 0407, p. 012, 2004.

[151] C. Dvorkin and W. Hu, "Generalized Slow Roll for Large Power Spectrum Features," *Phys.Rev.*, vol. D81, p. 023518, 2010.

[152] P. Adshead, W. Hu, C. Dvorkin, and H. V. Peiris, "Fast Computation of Bispectrum Features with Generalized Slow Roll," *Phys.Rev.*, vol. D84, p. 043519, 2011.

[153] L. Keldysh, "Diagram technique for nonequilibrium processes," *Zh.Eksp.Teor.Fiz.*, vol. 47, pp. 1515–1527, 1964.

[154] S. Weinberg, "Quantum contributions to cosmological correlations," *Phys.Rev.*, vol. D72, p. 043514, 2005.

[155] P. Creminelli and M. Zaldarriaga, "Single field consistency relation for the 3-point function," *JCAP*, vol. 0410, p. 006, 2004.

[156] A. Achúcarro, V. Atal, P. Ortiz, and J. Torrado, "Localized correlated features in the CMB power spectrum and primordial bispectrum from a transient reduction in the speed of sound," *Phys.Rev.*, vol. D89, p. 103006, 2014.

[157] P. Ade *et al.*, "Planck 2013 results. XVI. Cosmological parameters," 2013.

[158] D. Blas, J. Lesgourgues, and T. Tram, "The Cosmic Linear Anisotropy Solving System (CLASS) II: Approximation schemes," *JCAP*, vol. 1107, p. 034, 2011.

[159] P. Ade *et al.*, "Planck 2013 results. XV. CMB power spectra and likelihood," 2013.

[160] C. Bennett *et al.*, "Nine-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Final Maps and Results," *Astrophys.J.Suppl.*, vol. 208, p. 20, 2013.

[161] B. Audren, J. Lesgourgues, K. Benabed, and S. Prunet, "Conservative Constraints on Early Cosmology: an illustration of the Monte Python cosmological parameter inference code," *JCAP*, vol. 1302, p. 001, 2013.

[162] F. Feroz and M. Hobson, "Multimodal nested sampling: an efficient and robust alternative to MCMC methods for astronomical data analysis," *Mon.Not.Roy.Astron.Soc.*, vol. 384, p. 449, 2008.

[163] F. Feroz, M. Hobson, and M. Bridges, "MultiNest: an efficient and robust Bayesian inference tool for cosmology and particle physics," *Mon.Not.Roy.Astron.Soc.*, vol. 398, pp. 1601–1614, 2009.

[164] L. Verde, "Statistical methods in cosmology," *Lect.Notes Phys.*, vol. 800, pp. 147–177, 2010.

[165] P. Ade *et al.*, "Planck 2013 Results. XXIV. Constraints on primordial non-Gaussianity," 2013.

[166] X. Chen, R. Easther, and E. A. Lim, "Large Non-Gaussianities in Single Field Inflation," *JCAP*, vol. 0706, p. 023, 2007.

[167] S. Rubin, "Effect of massive fields on inflation," *Journal of Experimental and Theoretical Physics Letters*, vol. 74, no. 5, pp. 247–250, 2001.

[168] X. Dong, B. Horn, E. Silverstein, and A. Westphal, "Simple exercises to flatten your potential," *Phys.Rev.*, vol. D84, p. 026011, 2011.

[169] C. M. Peterson and M. Tegmark, "Testing Two-Field Inflation," *Phys.Rev.*, vol. D83, p. 023522, 2011.

[170] A. Achúcarro and Y. Welling, "Multiple Field Inflation and Signatures of Heavy Physics in the CMB," 2015.

[171] J. McDonald, "Sub-Planckian Two-Field Inflation Consistent with the Lyth Bound," *JCAP*, vol. 1409, no. 09, p. 027, 2014.

[172] G. Barenboim and W.-I. Park, "Spiral Inflation," *Phys.Lett.*, vol. B741, pp. 252–255, 2015.

[173] T. Li, Z. Li, and D. V. Nanopoulos, "Helical Phase Inflation," *Phys.Rev.*, vol. D91, no. 6, p. 061303, 2015.

[174] J. E. Kim, H. P. Nilles, and M. Peloso, "Completing natural inflation," *JCAP*, vol. 0501, p. 005, 2005.

[175] S. Dimopoulos, S. Kachru, J. McGreevy, and J. G. Wacker, "N-flation," *JCAP*, vol. 0808, p. 003, 2008.

[176] R. Kappl, H. P. Nilles, and M. W. Winkler, "Natural Inflation and Low Energy Supersymmetry," 2015.

[177] T. Li, Z. Li, and D. V. Nanopoulos, "Symmetry Breaking Indication for Supergravity Inflation in Light of the Planck 2015," 2015.

[178] C. Pallis, "Non-minimally gravity-coupled inflationary models," *Physics Letters B*, vol. 692, no. 5, pp. 287 – 296, 2010.

[179] R. Kallosh, A. Linde, and D. Roest, "Universal Attractor for Inflation at Strong Coupling," *Phys.Rev.Lett.*, vol. 112, no. 1, p. 011303, 2014.

[180] A. Ashoorioon, K. Dimopoulos, M. Sheikh-Jabbari, and G. Shiu, "Reconciliation of High Energy Scale Models of Inflation with Planck," *JCAP*, vol. 1402, p. 025, 2014.

[181] K. Kannike, G. H?tsi, L. Pizza, A. Racioppi, M. Raidal, *et al.*, "Dynamically Induced Planck Scale and Inflation," *JHEP*, vol. 1505, p. 065, 2015.

[182] L. Boubekeur, E. Giusarma, O. Mena, and H. Ram?rez, "Does Current Data Prefer a Non-minimally Coupled Inflaton?," *Phys.Rev.*, vol. D91, p. 103004, 2015.

[183] W. Buchmuller, E. Dudas, L. Heurtier, A. Westphal, C. Wieck, *et al.*, "Challenges for Large-Field Inflation and Moduli Stabilization," *JHEP*, vol. 1504, p. 058, 2015.

[184] L. McAllister, E. Silverstein, and A. Westphal, "Gravity Waves and Linear Inflation from Axion Monodromy," *Phys.Rev.*, vol. D82, p. 046003, 2010.

[185] N. Kaloper and L. Sorbo, "A Natural Framework for Chaotic Inflation," *Phys.Rev.Lett.*, vol. 102, p. 121301, 2009.

[186] N. Kaloper, A. Lawrence, and L. Sorbo, "An Ignoble Approach to Large Field Inflation," *JCAP*, vol. 1103, p. 023, 2011.

[187] K. Harigaya and M. Ibe, "Simple realization of inflaton potential on a Riemann surface," *Phys.Lett.*, vol. B738, pp. 301–304, 2014.

[188] I. Zavala, "Effects of the speed of sound at large-N," *Phys.Rev.*, vol. D91, no. 6, p. 063005, 2015.

[189] R. Gwyn, G. A. Palma, M. Sakellariadou, and S. Sypsas, "On degenerate models of cosmic inflation," *JCAP*, vol. 1410, no. 10, p. 005, 2014.

[190] M. Dias, J. Frazer, and D. Seery, "Computing observables in curved multifield models of inflation - A guide (with code) to the transport method," 2015.

[191] T. Banks, M. Dine, P. J. Fox, and E. Gorbatov, "On the possibility of large axion decay constants," *JCAP*, vol. 0306, p. 001, 2003.

[192] R. D. Peccei and H. R. Quinn, "CP Conservation in the Presence of Instantons," *Phys. Rev. Lett.*, vol. 38, pp. 1440–1443, 1977.

[193] R. D. Peccei and H. R. Quinn, "Constraints Imposed by CP Conservation in the Presence of Instantons," *Phys. Rev.*, vol. D16, pp. 1791–1797, 1977.

[194] S. Weinberg, "A New Light Boson?," *Phys. Rev. Lett.*, vol. 40, pp. 223–226, 1978.

[195] F. Wilczek, "Problem of Strong p and t Invariance in the Presence of Instantons," *Phys. Rev. Lett.*, vol. 40, pp. 279–282, 1978.

[196] M. Dine, P. Draper, and A. Monteux, "Monodromy Inflation in SUSY QCD," *JHEP*, vol. 07, p. 146, 2014.

[197] K. Yonekura, "Notes on natural inflation," *JCAP*, vol. 1410, no. 10, p. 054, 2014.

[198] A. Albrecht, R. Holman, and B. J. Richard, "Spinodal Instabilities and Super-Planckian Excursions in Natural Inflation," *Phys. Rev. Lett.*, vol. 114, p. 171301, 2015.

[199] M. Czerny and F. Takahashi, "Multi-Natural Inflation," *Phys. Lett.*, vol. B733, pp. 241–246, 2014.

[200] M. Peloso and C. Unal, "Trajectories with suppressed tensor-to-scalar ratio in Aligned Natural Inflation," *JCAP*, vol. 1506, no. 06, p. 040, 2015.

[201] M. Czerny, T. Higaki, and F. Takahashi, "Multi-Natural Inflation in Supergravity," *JHEP*, vol. 05, p. 144, 2014.

[202] D. Croon and V. Sanz, "Saving Natural Inflation," *JCAP*, vol. 1502, no. 02, p. 008, 2015.

[203] J. McDonald, "A Minimal Sub-Planckian Axion Inflation Model with Large Tensor-to-Scalar Ratio," *JCAP*, vol. 1501, no. 01, p. 018, 2015.

[204] T. Higaki and F. Takahashi, "Elliptic inflation: interpolating from natural inflation to R^2-inflation," *JHEP*, vol. 03, p. 129, 2015.

[205] I. P. Neupane, "Natural Braneworld Inflation in Light of Recent Results from Planck and BICEP2," *Phys. Rev.*, vol. D90, no. 12, p. 123502, 2014.

[206] E. Dudas and C. Wieck, "Moduli backreaction and supersymmetry breaking in string-inspired inflation models," 2015.

[207] T. Li, Z. Li, and D. V. Nanopoulos, "Helical Phase Inflation via Non-Geometric Flux Compactifications: from Natural to Starobinsky-like Inflation," 2015.

[208] A. Achúcarro, V. Atal, and Y. Welling, "On the viability of $m^2\phi^2$ and natural inflation," *JCAP*, vol. 1507, p. 008, 2015.

[209] J. D. Cohn and E. D. Stewart, "NonAbelian discrete gauge symmetries and inflation," *Phys. Lett.*, vol. B475, pp. 231–235, 2000.

[210] G. G. Ross and G. German, "Hybrid natural inflation from non Abelian discrete symmetry," *Phys. Lett.*, vol. B684, pp. 199–204, 2010.

[211] C. P. Burgess, M. Cicoli, F. Quevedo, and M. Williams, "Inflating with Large Effective Fields," *JCAP*, vol. 1411, p. 045, 2014.

[212] C. Burgess and D. Roest, "Inflation by Alignment," *JCAP*, vol. 1506, no. 06, p. 012, 2015.

[213] D. Croon, V. Sanz, and J. Setford, "Goldstone Inflation," 2015.

[214] R. Kallosh, A. D. Linde, D. A. Linde, and L. Susskind, "Gravity and global symmetries," *Phys. Rev.*, vol. D52, pp. 912–935, 1995.

[215] S. G. Rubin, "Effect of massive fields on inflation," *JETP Lett.*, vol. 74, pp. 247–250, 2001. [Pisma Zh. Eksp. Teor. Fiz.74,275(2001)].

[216] C. R. Contaldi, M. Peloso, L. Kofman, and A. D. Linde, "Suppressing the lower multipoles in the CMB anisotropies," *JCAP*, vol. 0307, p. 002, 2003.

[217] M. Cicoli, S. Downes, and B. Dutta, "Power Suppression at Large Scales in String Inflation," *JCAP*, vol. 1312, p. 007, 2013.

[218] F. G. Pedro and A. Westphal, "Low-ℓ CMB power loss in string inflation," *JHEP*, vol. 1404, p. 034, 2014.

[219] R. Bousso, D. Harlow, and L. Senatore, "Inflation after False Vacuum Decay: Observational Prospects after Planck," *Phys. Rev.*, vol. D91, no. 8, p. 083527, 2015.

[220] J. J. Blanco-Pillado, M. Dias, J. Frazer, and K. Sousa, "Large Scale Power Suppression in a Multifield Landscape," 2015.

Publications

- *The two-field regime of natural inflation*, A. Achúcarro, V. Atal and M. Kawasaki, F. Takahashi, JCAP **1512** (2015) 12, 044 [arXiv:1510.08775 [astro-ph.CO]].

- *On the viability of $m^2\phi^2$ and natural inflation*, A. Achúcarro, V. Atal and Y. Welling, JCAP **1507** (2015) 07, 008 [arXiv:1503.07486 [astro-ph.CO]].

- *Inflation with moderately sharp features in the speed of sound: Generalized slow roll and in-in formalism for power spectrum and bispectrum*, A. Achúcarro, V. Atal, B. Hu, P. Ortiz and J. Torrado, Phys. Rev. D **90** (2014) 2, 023511 [arXiv:1404.7522 [astro-ph.CO]].

- *"Localized correlated features in the CMB power spectrum and primordial bispectrum from a transient reduction in the speed of sound,"*, A. Achúcarro, V. Atal, P. Ortiz and J. Torrado, Phys. Rev. D **89** (2014) 10, 103006 [arXiv:1311.2552 [astro-ph.CO]].

- *"Heavy fields, reduced speeds of sound and decoupling during inflation"*, A. Achúcarro, V. Atal, S. Céspedes, J. O. Gong, G. A. Palma and S. P. Patil, Phys. Rev. D **86** (2012) 121301 [arXiv:1205.0710 [hep-th]].

- *"On the importance of heavy fields during inflation"*, S. Céspedes, V. Atal and G. A. Palma, JCAP **1205** (2012) 008 [arXiv:1201.4848 [hep-th]].

- *"Bigravitational inflation"*, V. Atal, L. E. Campusano and G. A. Palma, Phys. Rev. D **86** (2012) 123521 [arXiv:1109.3224 [hep-th]].