University of Sussex

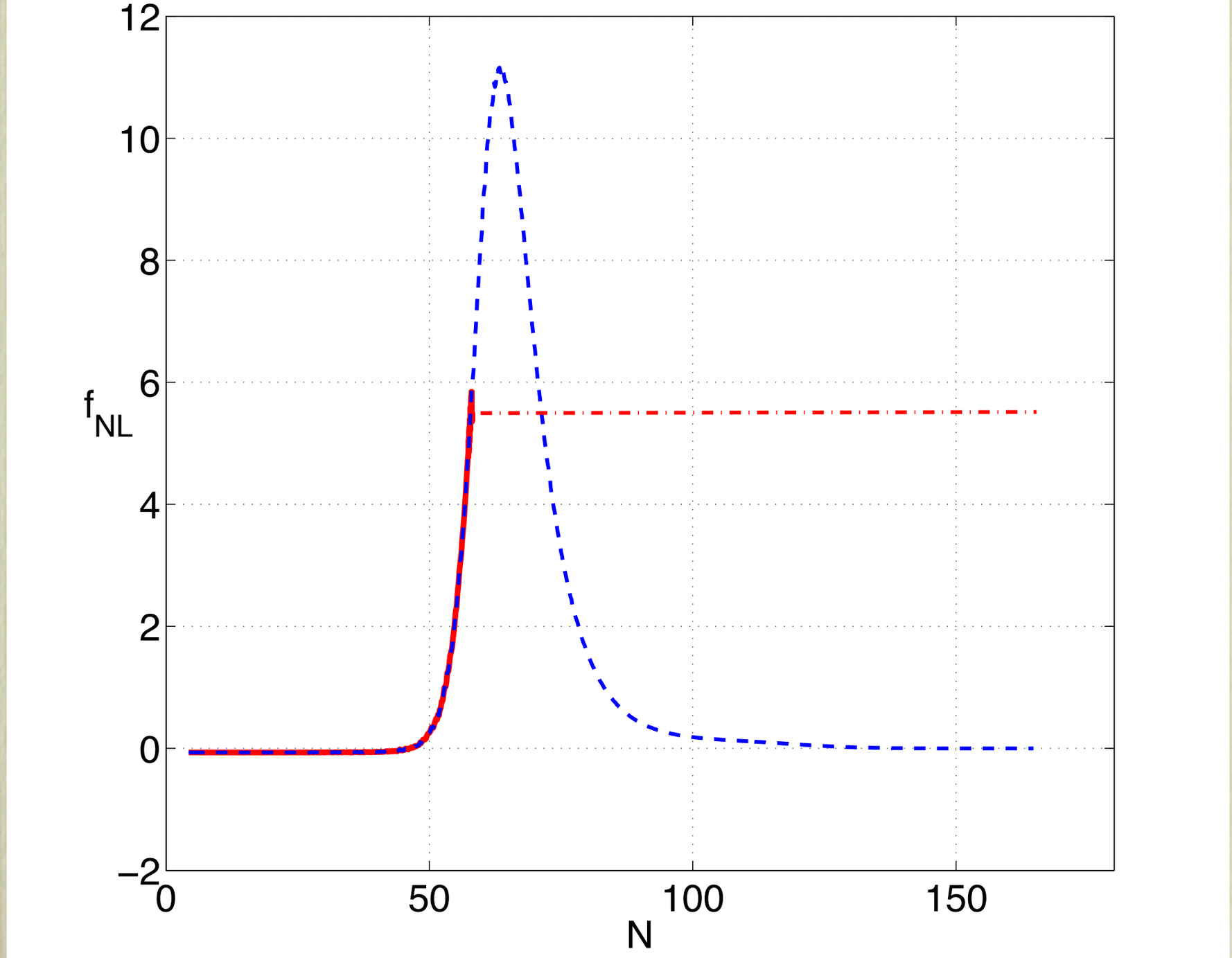
Analytic reheating

Joseph Elliston
University of Sussex

arXiv: 1402.4800

In collaboration with Stefano Orani and David Mulryne

Reheating matters...



J. Elliston, D. J. Mulryne, D. Seery, and R. Tavakol, JCAP **1111**, 005 (2011), 1106.2153.

G. Leung, E. R. Tarrant, C. T. Byrnes, and E. J. Copeland, JCAP **1209**, 008 (2012), 1206.5196.
J. Meyers and E. R. M. Tarrant (2013), 1311.3972.

Our result encapsulates:

Two-field slow-roll inflation

Curvaton-type

Inhomogeneous End of Inflation

Modulated Reheating

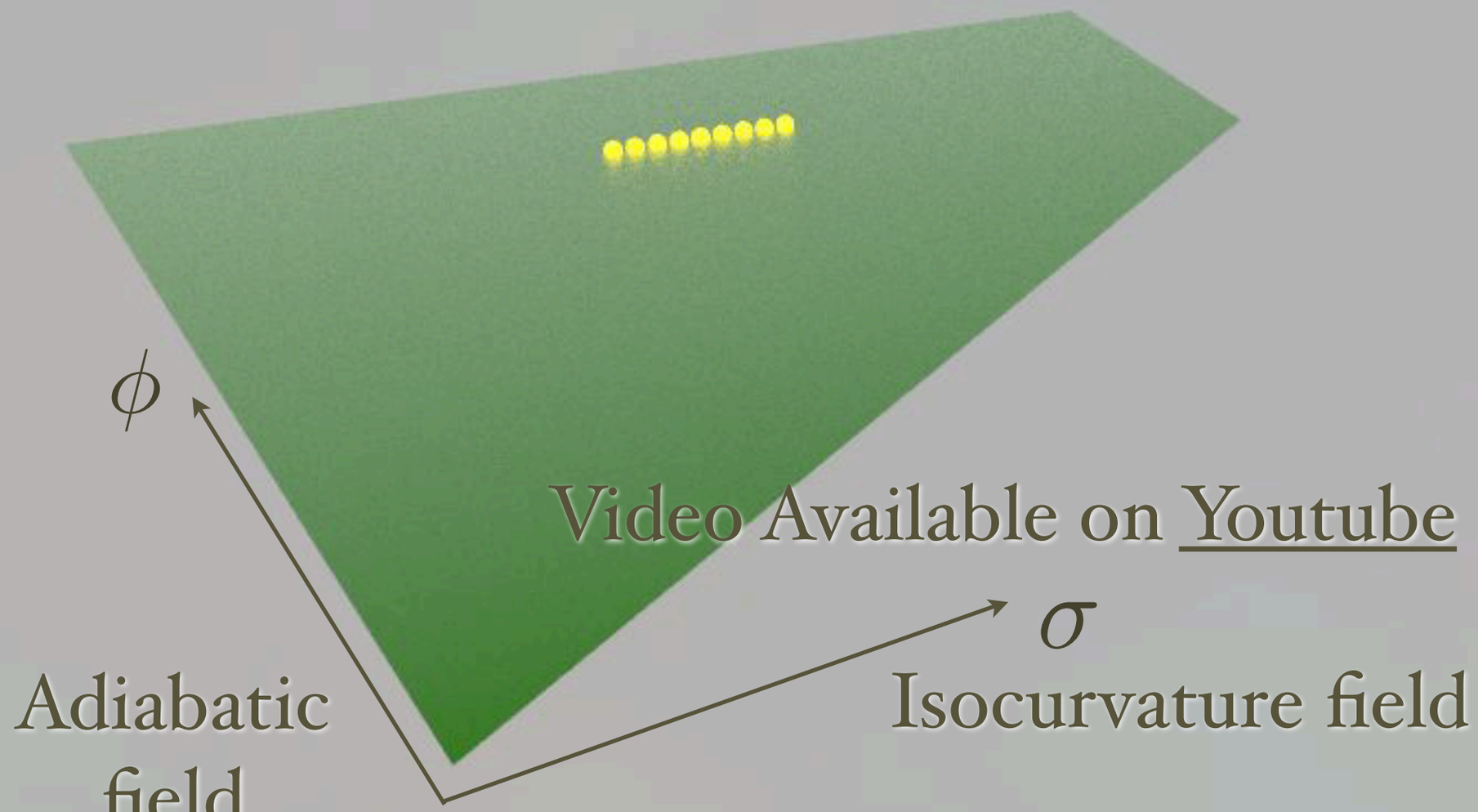
F. Bernardeau and J.-P. Uzan, Phys.Rev. **D66**, 103506 (2002), hep-ph/0207295.
G. Rigopoulos, E. Shellard, and B. van Tent, Phys.Rev. **D76**, 083512 (2007), astro-ph/0511041.
F. Vernizzi and D. Wands, JCAP **0605**, 019 (2006), astro-ph/0603799.
L. Alabidi, JCAP **0610**, 015 (2006), astro-ph/0604611.
C. T. Byrnes, K.-Y. Choi, and L. M. Hall, JCAP **0810**, 008 (2008), 0807.1101.
J. Elliston, D. J. Mulryne, D. Seery, and R. Tavakol, JCAP **1111**, 005 (2011), 1106.2153.
J. Elliston, L. Alabidi, I. Huston, D. Mulryne, and R. Tavakol, JCAP **1209**, 001 (2012), 1203.6844.
T. Tanaka, T. Suyama, and S. Yokoyama, Class.Quant.Grav. **27**, 124003 (2010), 1003.5057.
C. M. Peterson and M. Tegmark, Phys. Rev. **D84**, 023520 (2011), 1011.6675.
S. A. Kim, A. R. Liddle, and D. Seery, Phys.Rev.Lett. **105**, 181302 (2010), 1005.4410.
D. Mulryne, S. Orani, and A. Rajantie, Phys.Rev. **D84**, 123527 (2011), 1107.4739.

K. Enqvist and M. S. Sloth, Nucl.Phys. **B626**, 395 (2002), hep-ph/0109214.
D. H. Lyth and D. Wands, Phys.Lett. **B524**, 5 (2002), hep-ph/0110002.
T. Moroi and T. Takahashi, Phys.Lett. **B522**, 215 (2001), hep-ph/0110096.
K. Enqvist and S. Nurmi, JCAP **0510**, 013 (2005), astro-ph/0508573.
A. D. Linde and V. Mukhanov, JCAP **0604**, 009 (2006), astro-ph/0511736.
K. A. Malik and D. H. Lyth, JCAP **0609**, 008 (2006), astro-ph/0604387.
M. Sasaki, J. Valiviita, and D. Wands, Phys.Rev. **D74**, 103003 (2006), astro-ph/0607627.
S. Mollerach, Phys.Rev. **D42**, 313 (1990).
A. D. Linde and V. F. Mukhanov, Phys.Rev. **D56**, 535 (1997), astro-ph/9610219.

F. Bernardeau and J.-P. Uzan, Phys.Rev. **D67**, 121301 (2003), astro-ph/0209330.
D. H. Lyth, JCAP **0511**, 006 (2005), astro-ph/0510443.
M. P. Salem, Phys.Rev. **D72**, 123516 (2005), astro-ph/0511146.
L. Alabidi and D. Lyth, JCAP **0608**, 006 (2006), astro-ph/0604569.
F. Bernardeau and T. Brunier, Phys.Rev. **D76**, 043526 (2007), 0705.2501.
M. Sasaki, Prog.Theor.Phys. **120**, 159 (2008), 0805.0974.
A. Naruko and M. Sasaki, Prog.Theor.Phys. **121**, 193 (2009), 0807.0180.

G. Dvali, A. Gruzinov, and M. Zaldarriaga, Phys.Rev. **D69**, 023505 (2004), astro-ph/0303591.
M. Zaldarriaga, Phys.Rev. **D69**, 043508 (2004), astro-ph/0306006.
L. Kofman (2003), astro-ph/0303614.
F. Vernizzi, Phys.Rev. **D69**, 083526 (2004), astro-ph/0311167.
F. Bernardeau, L. Kofman, and J.-P. Uzan, Phys.Rev. **D70**, 083004 (2004), astro-ph/0403315.
K. Ichikawa, T. Suyama, T. Takahashi, and M. Yamaguchi, Phys.Rev. **D78**, 063545 (2008), 0807.3988.
C. T. Byrnes, JCAP **0901**, 011 (2009), 0810.3913.
T. Suyama and M. Yamaguchi, Phys.Rev. **D77**, 023505 (2008), 0709.2545.

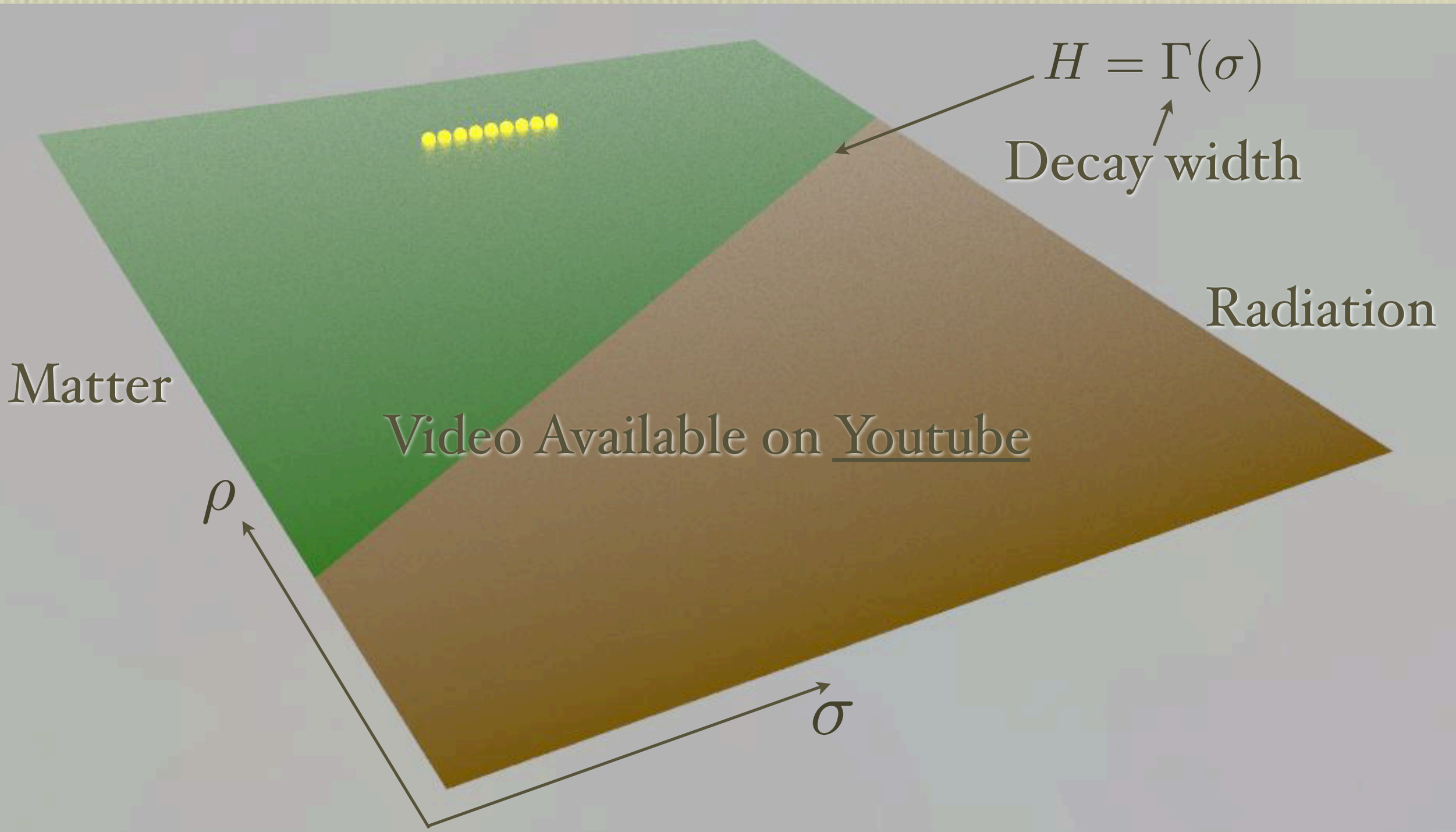
Inhomogeneous End of Inflation



Video Available on Youtube

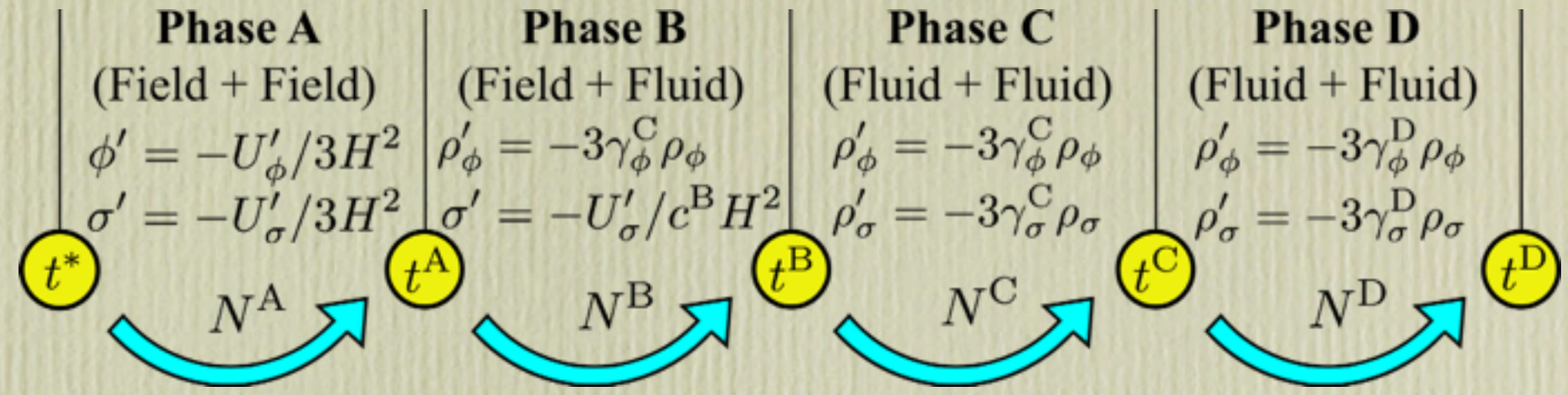
$$\zeta = \delta N$$

Modulated Reheating



Equivalence between Inhomogeneous End of Inflation and Modulated Reheating: see arXiv: 1307.7095

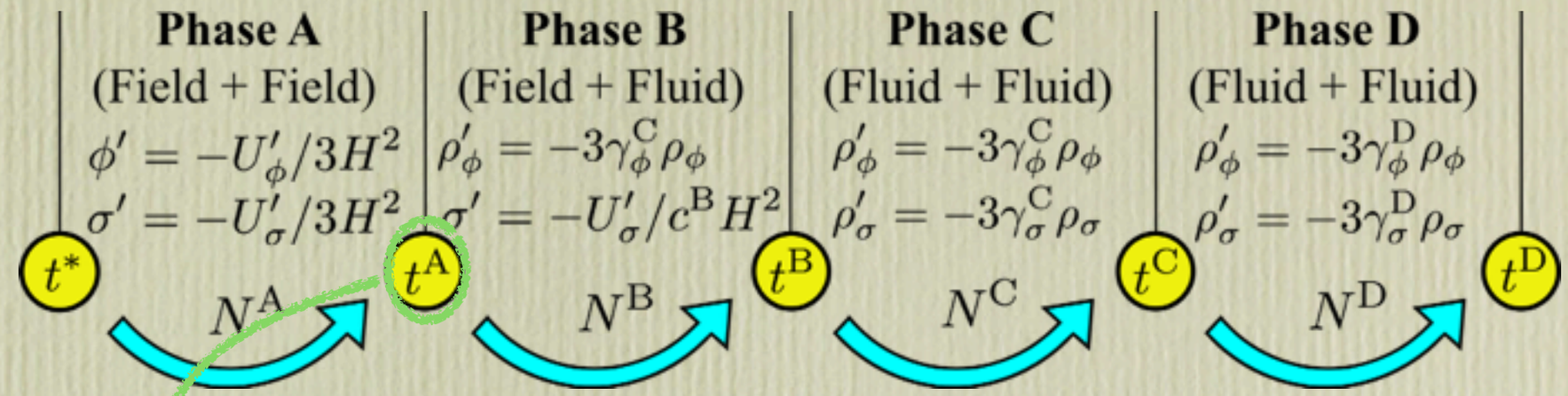
Analytic calculations...



$$N = -\int_*^{\rm A} \frac{U_\phi}{M_{\rm pl}^2 U'_\phi}\,{\rm d}\phi - \int_*^{\rm A} \frac{U_\sigma}{M_{\rm pl}^2 U'_\sigma}\,{\rm d}\sigma$$
$$- \frac{1}{3\gamma_\phi^{\rm C}} \ln\frac{\rho_\phi^{\rm C}}{\rho_\phi^{\rm A}} - \frac{1}{3\gamma_\phi^{\rm D}} \ln\frac{\rho_\phi^{\rm D}}{\rho_\phi^{\rm C}}\,.$$

Phase A is just repeating Vernizzi and Wands (2006)...

Analytic calculations...



Allows arbitrary hypersurfaces

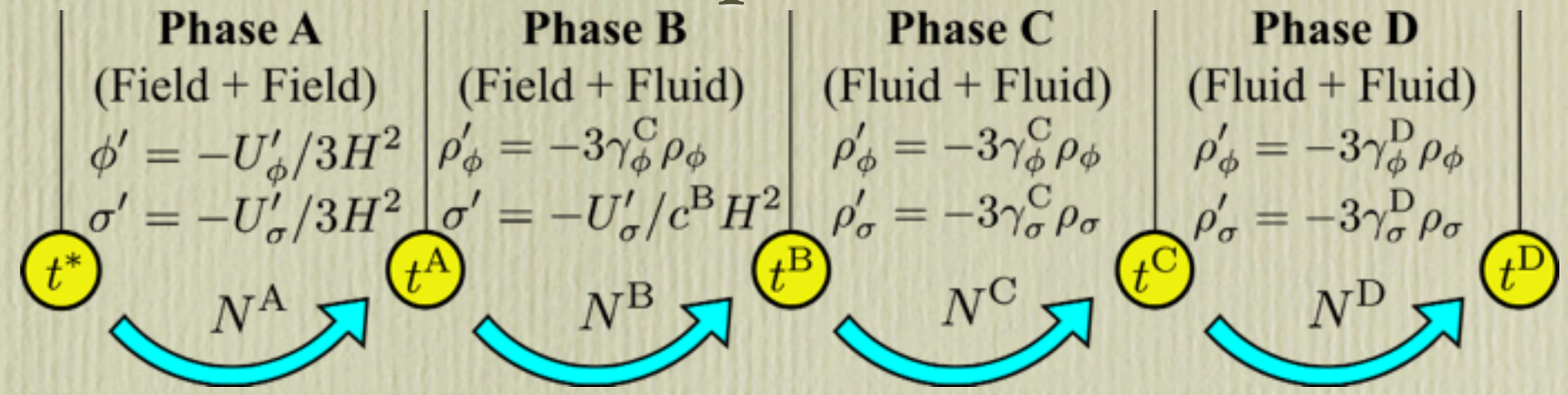
$$\int_*^{\rm A} \frac{1}{U'_\phi}\,{\rm d}\phi = \int_*^{\rm A} \frac{1}{U'_\sigma}\,{\rm d}\sigma\,.$$

$$\frac{1}{U'_\phi{}^{\rm A} r^{\rm A}}\delta\phi^{\rm A} = \frac{-1}{U'_\sigma{}^{\rm A}(1-r^{\rm A})}\delta\sigma^{\rm A} = \frac{\delta\phi^*}{U'_\phi{}^*} - \frac{\delta\sigma^*}{U'_\sigma{}^*}$$

$$r = \frac{\rho'_\sigma}{\rho'_{\rm total}}$$

(uniform density limit)

Principle result



"Oscillation parameter" degenerate with r

Modulation effects =1 if standard curvaton

$$\delta N = \left[\frac{U^{\rm A}_\sigma}{M^2_{\rm pl}} + \frac{1-x_\phi}{M^2_{\rm pl}x_\phi}\rho^{\rm A} r^{\rm A} - \mathcal{Q}^{\rm A}\mathcal{Q}^{\rm B}\mathcal{Q}^{\rm C}\mathcal{Q}^{\rm S}\frac{r^{\rm D}}{3\gamma^{\rm D}_\sigma}\frac{U'^{\,2}_\sigma{}^{\rm B}}{U^{\rm B}_\sigma}\right] \times \left(\frac{\delta\phi_*}{U'^{\,*}_\phi} - \frac{\delta\sigma_*}{U'^{\,*}_\sigma}\right) + \delta N_{\rm HCA}$$

Horizon Crossing Approximation piece (constant)

S. A. Kim and A. R. Liddle, Phys.Rev. **D74**, 063522 (2006), astro-ph/0608186.
S. A. Kim, A. R. Liddle, and D. Seery, Phys.Rev.Lett. **105**, 181302 (2010), 1005.4410.

Conclusions

arXiv: 1402.4800

- Reheating can alter the predictions of inflation
- We have a general but simple formula for perturbative reheating with two-components
- Combines the Curvaton, Inhomogeneous End of Inflation and Modulated Reheating models.
- Our work is a test bed for investigating the analytic criterion for phase transitions.