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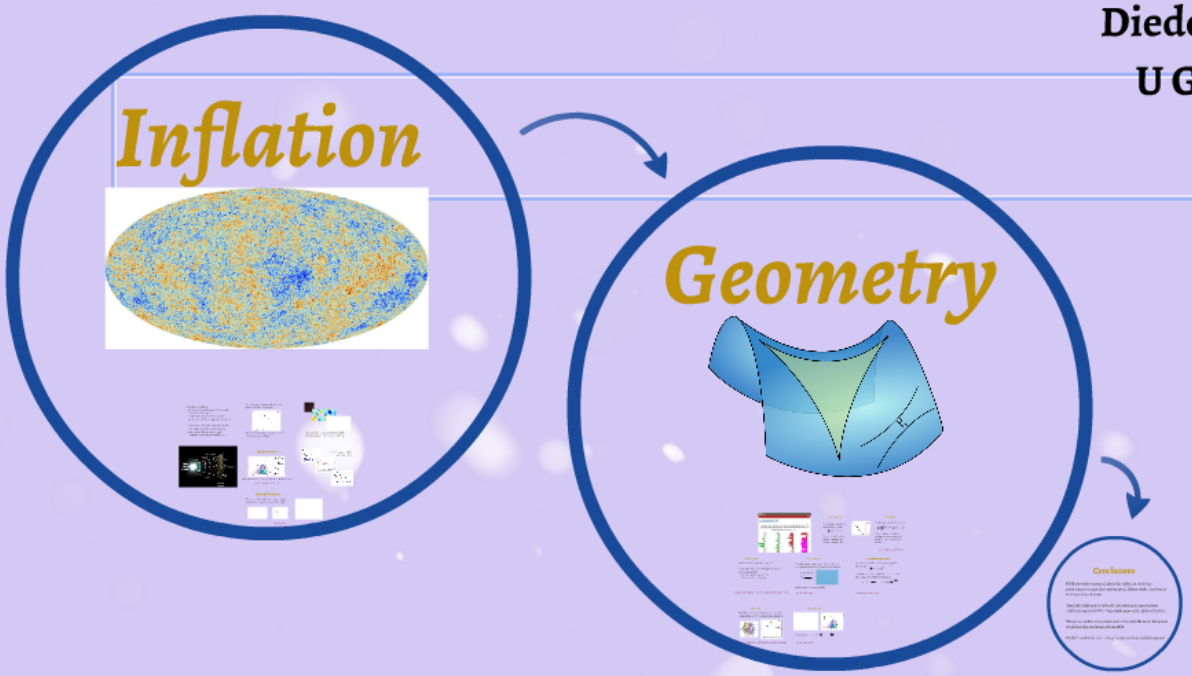

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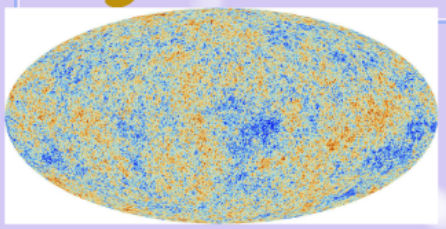
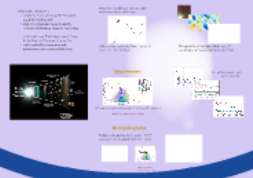
Inflation





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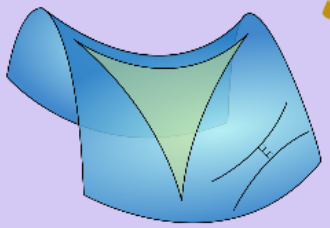

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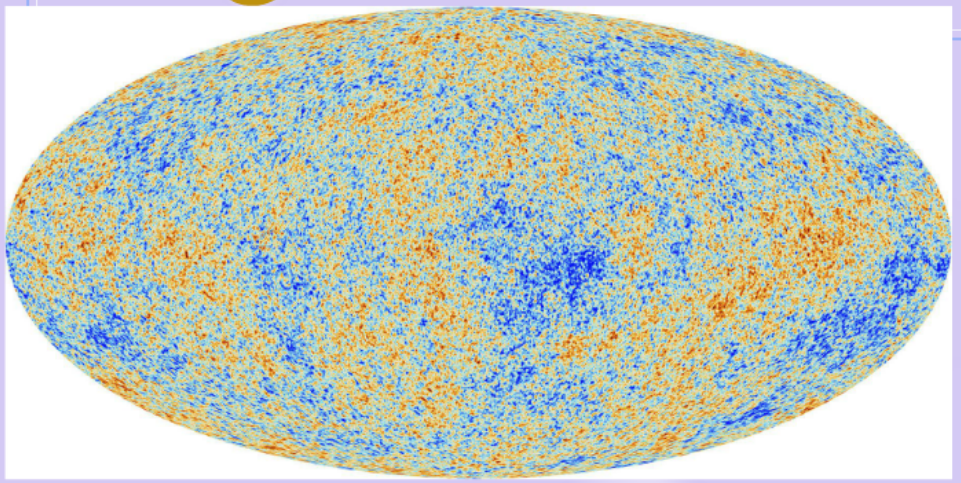
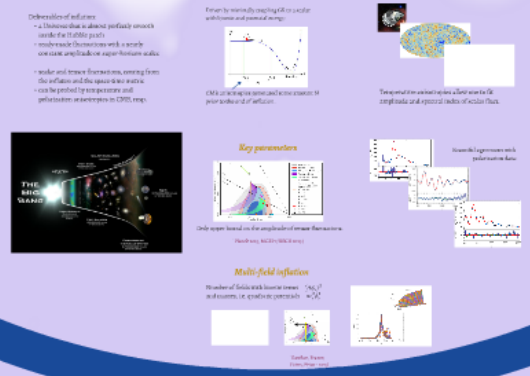
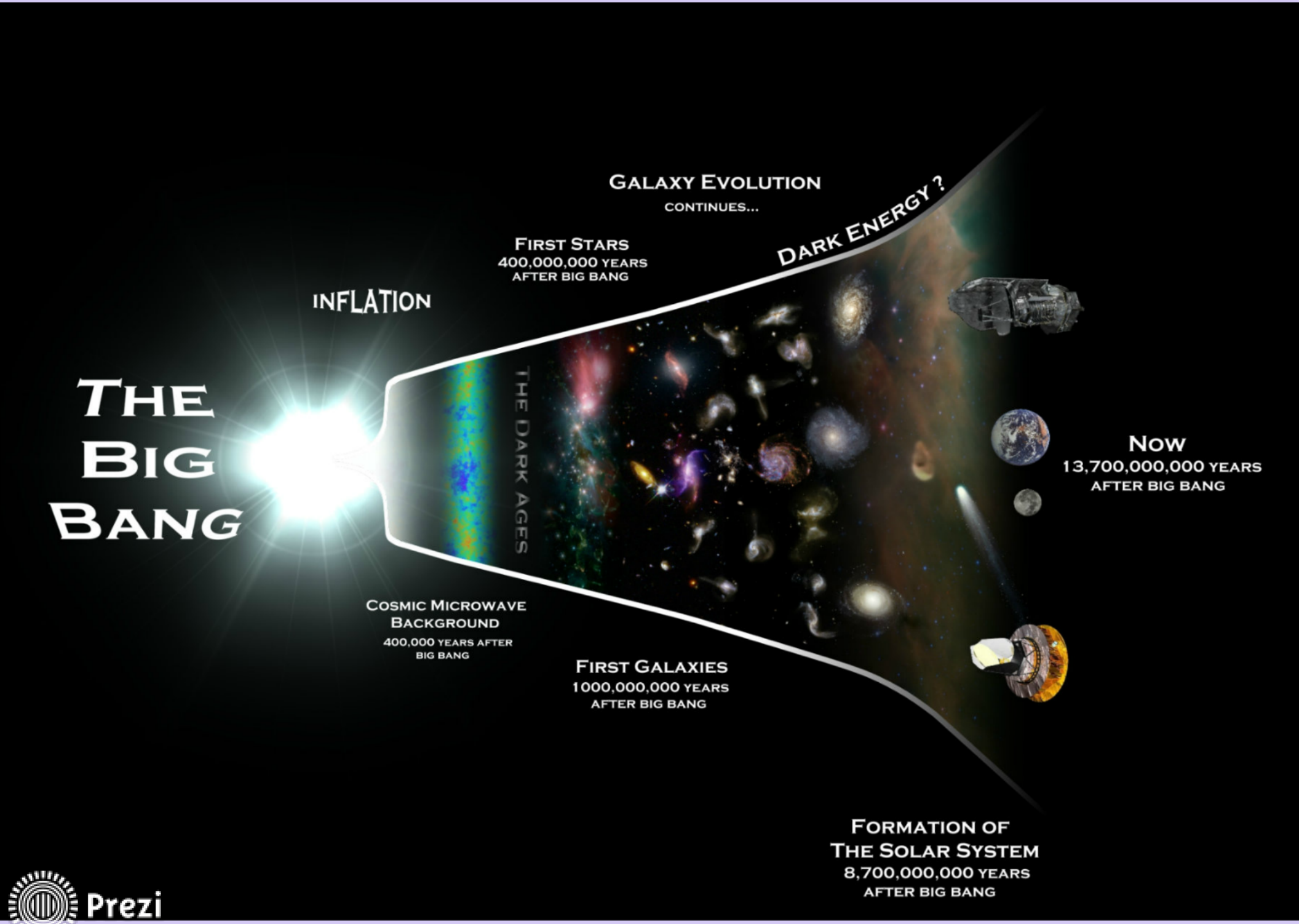




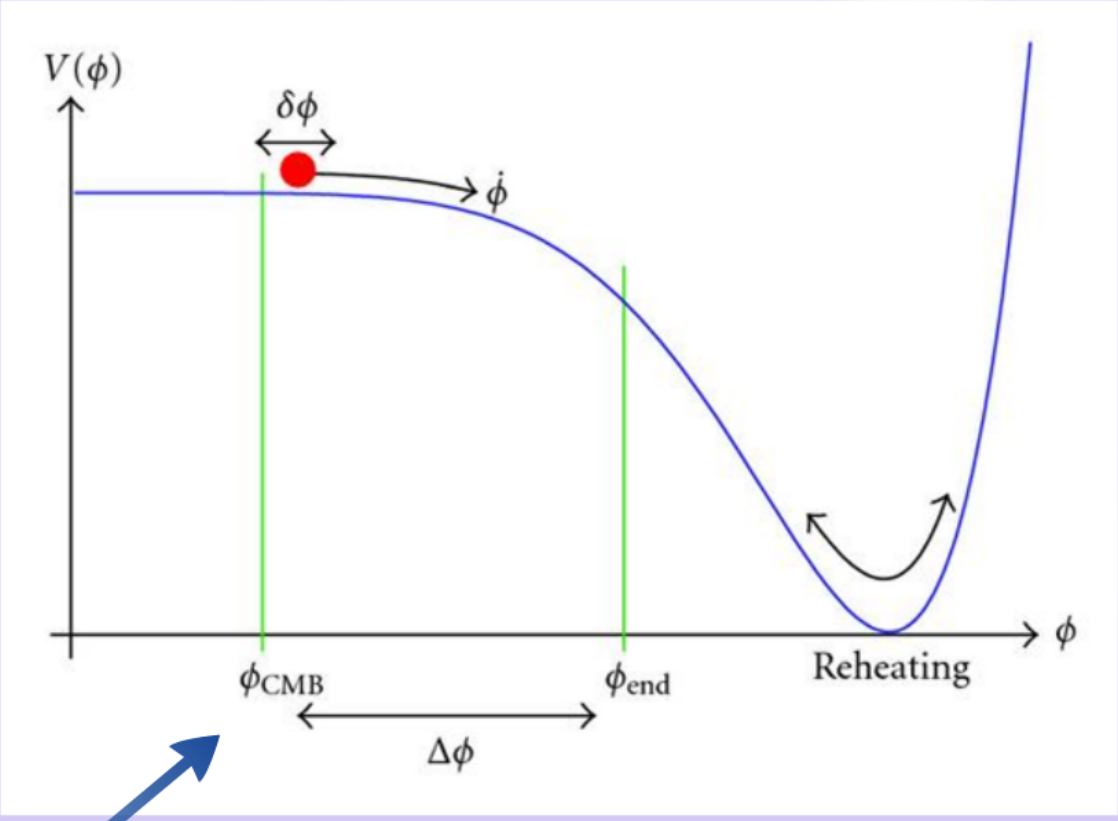

THE BIG BANG
INFLATION
FIRST STARS
400,000,000 YEARS
AFTER BIG BANG
GALAXY EVOLUTION
CONTINUES...
DARK ENERGY ?
THE DARK AGES
COSMIC MICROWAVE
BACKGROUND
400,000 YEARS AFTER
BIG BANG
FIRST GALAXIES
1000,000,000 YEARS
AFTER BIG BANG
NOW
13,700,000,000 YEARS
AFTER BIG BANG
FORMATION OF
THE SOLAR SYSTEM
8,700,000,000 YEARS
AFTER BIG BANG

Deliverables of inflation:

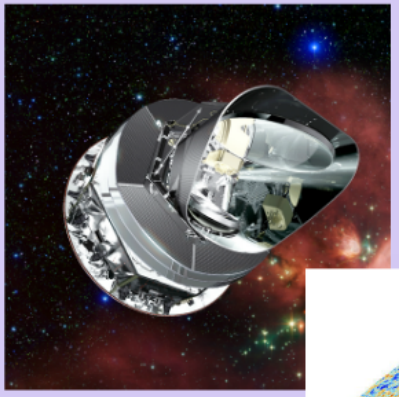
- a Universe that is almost perfectly smooth inside the Hubble patch
- ready-made fluctuations with a nearly constant amplitude on super-horizon scales

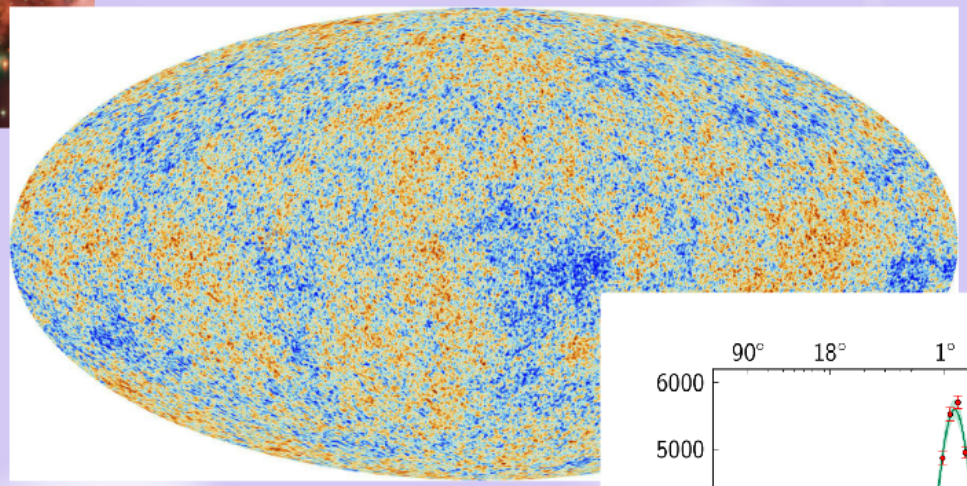
- scalar and tensor fluctuations, coming from the inflaton and the space-time metric
- can be probed by temperature and polarization anisotropies in CMB, resp.

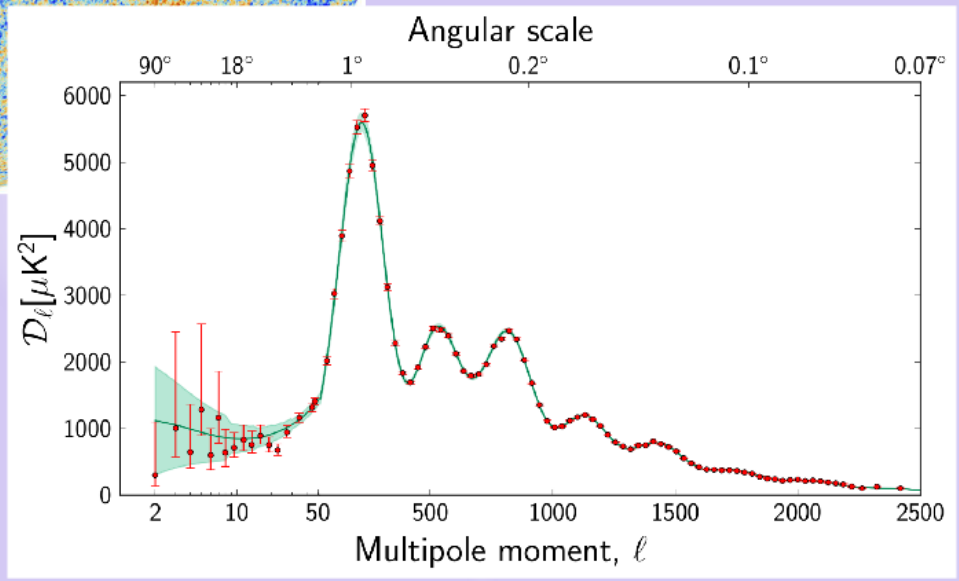
Driven by minimally coupling GR to a scalar with kinetic and potential energy:



CMB anisotropies generated some amount N prior to the end of inflation.

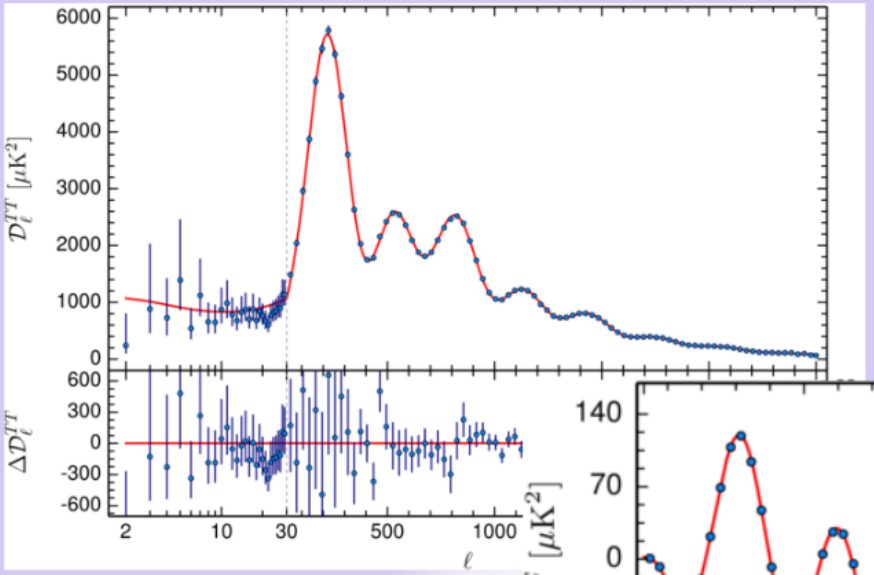


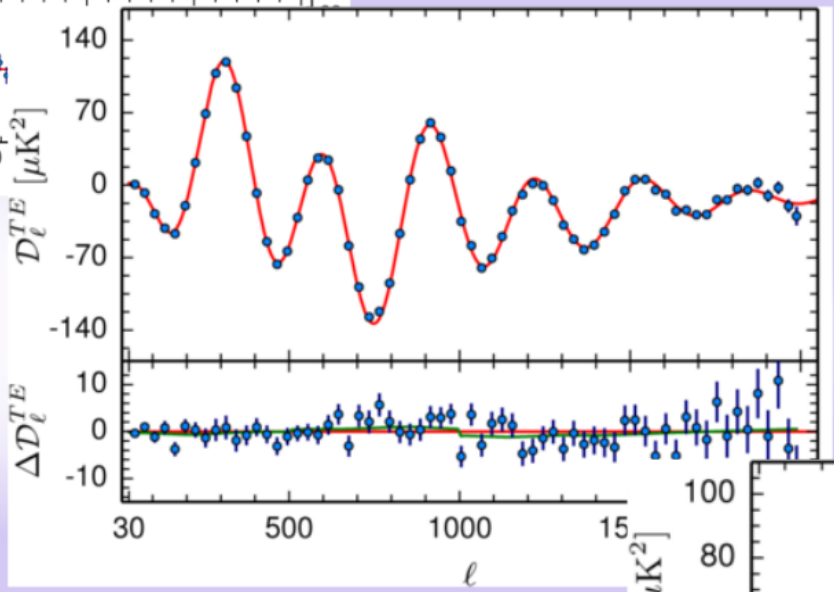


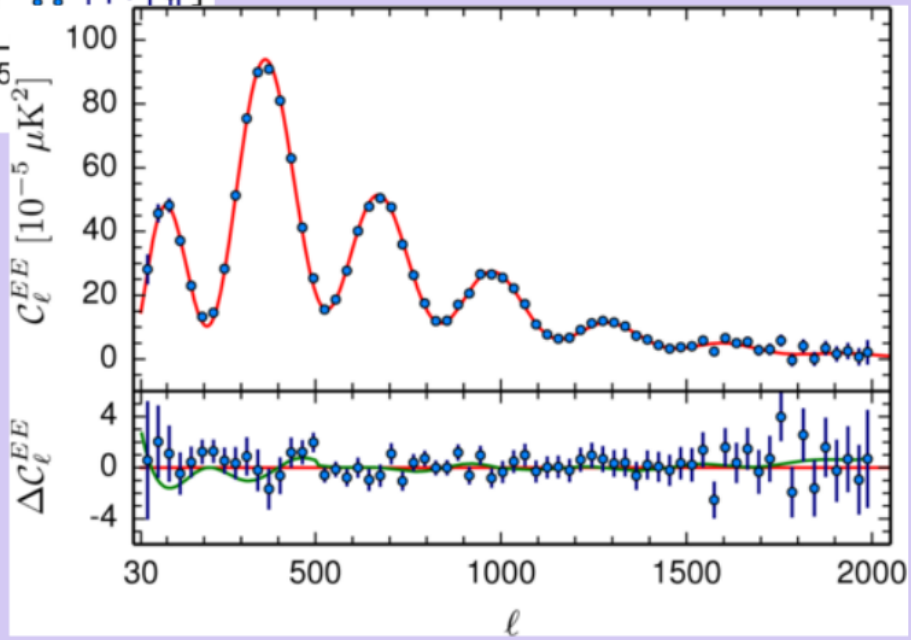


Temperature anisotropies allow one to fit amplitude and spectral index of scalar fluct.

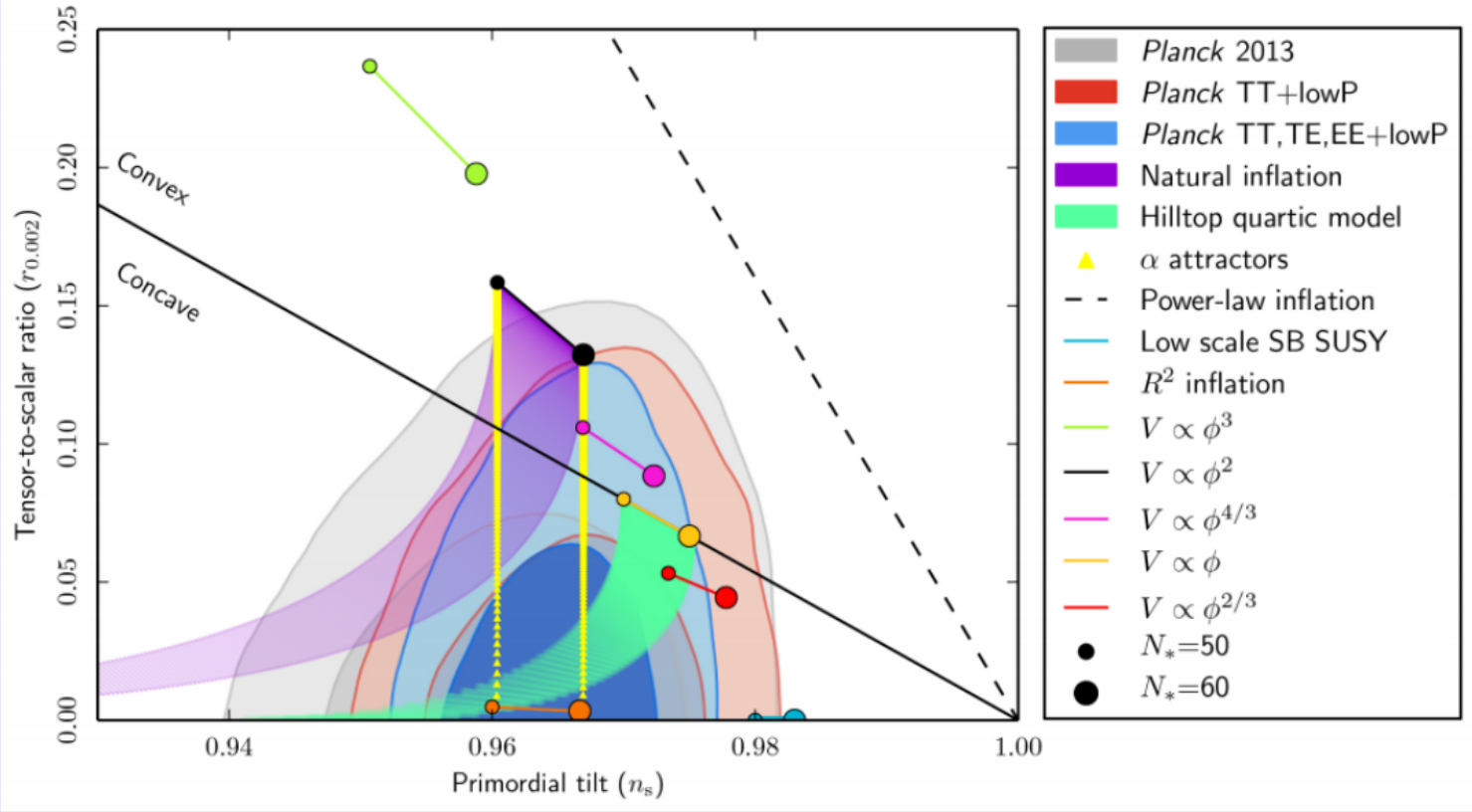
Beautiful agreement with polarization data:







Key parameters



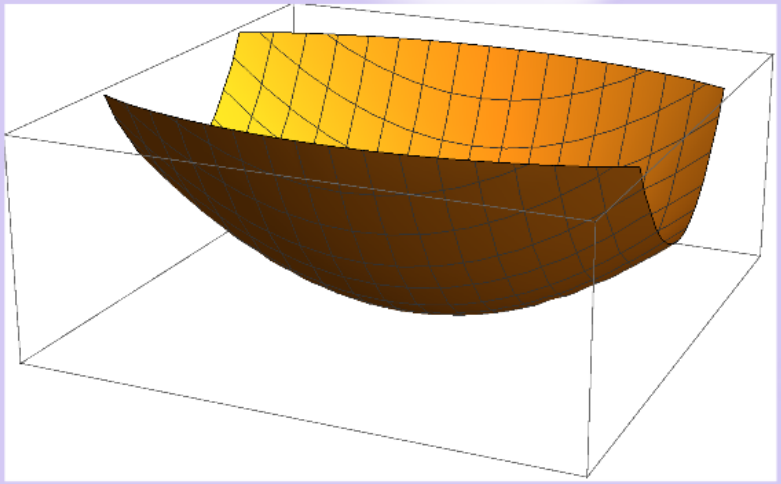
Only upper bound on the amplitude of tensor fluctuations.

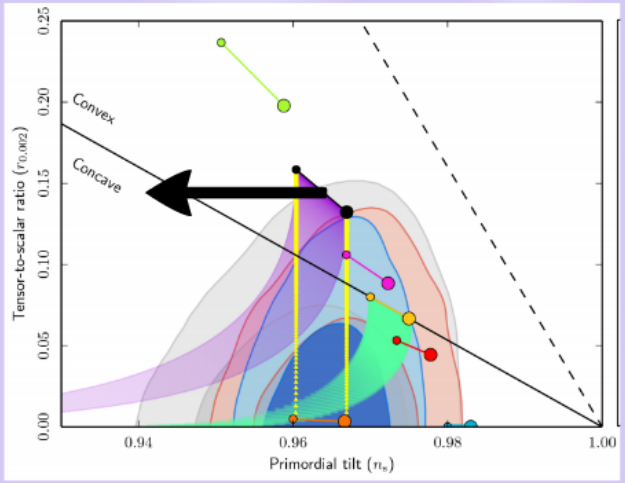
[Planck 2015, BICEP2/KECK 2015]

Multi-field inflation

Number of fields with kinetic terms $(\partial\phi_i)^2$

and masses, i.e. quadratic potentials $m_i^2\phi_i^2$



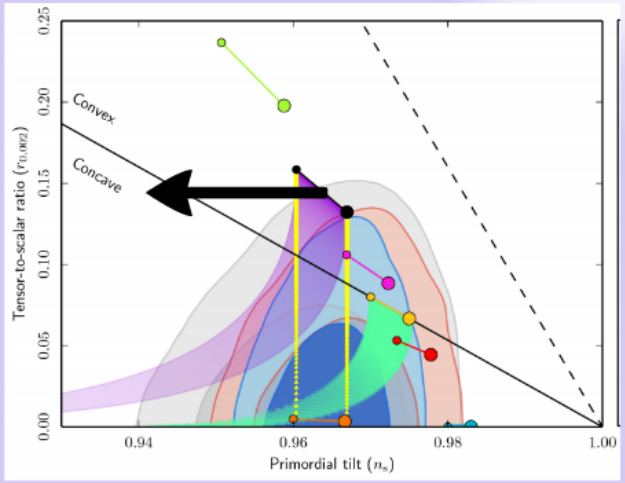


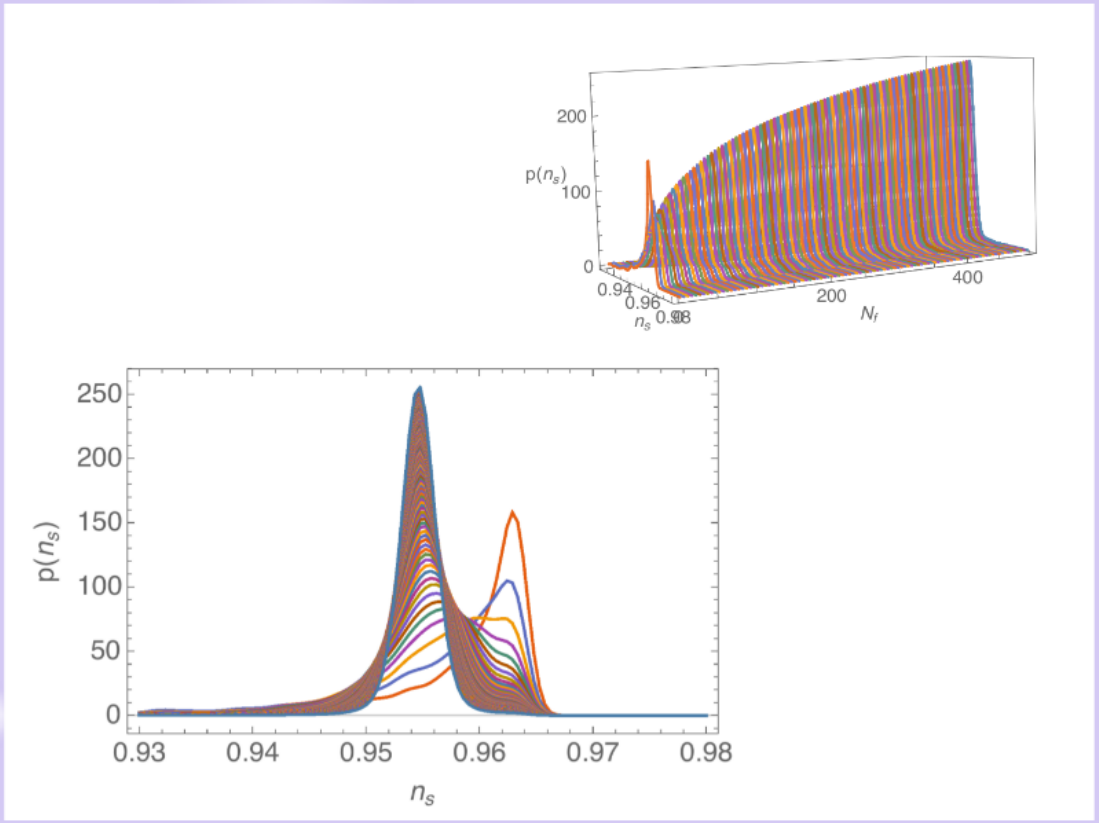
[Easther, Frazer, Peiris, Price - 2013]

inflation

tic terms $(\partial\phi_i)^2$

otentials $m_i^2\phi_i^2$





[Easther, Frazer, Peiris, Price - 2013]

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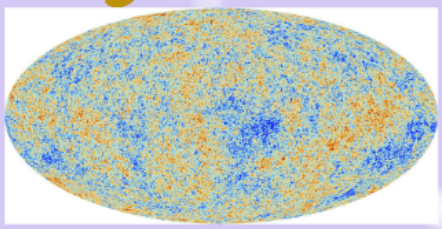
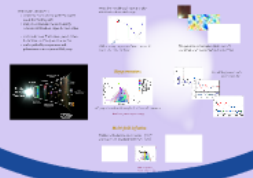
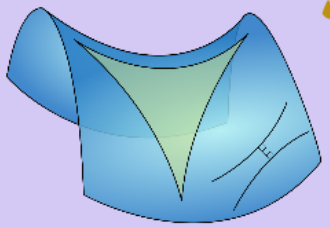
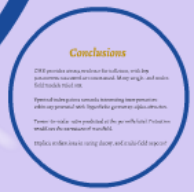




Geometry





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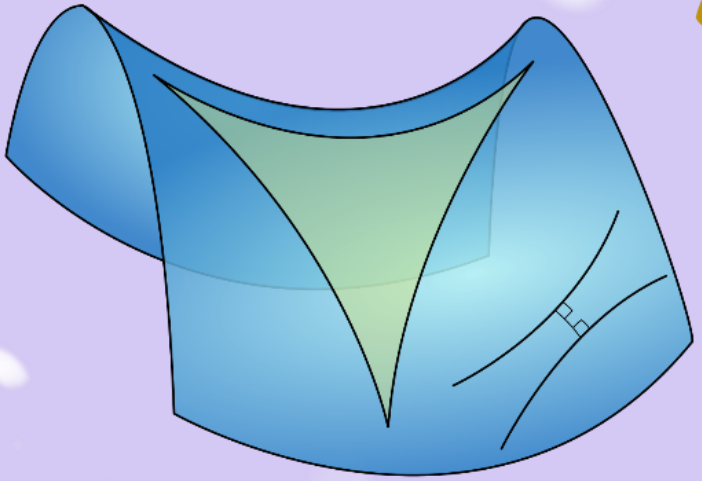
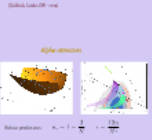
Geometry





Conclusions

CMB provides strong evidence for inflation, with key parameters measured or constrained. Many single- and multi-field models ruled out.

Spectral index points towards interesting interpretation: arbitrary potential with hyperbolic geometry: *alpha-attractors*.

Tensor-to-scalar ratio predicted at the permille level. Detection would set the curvature of manifold.

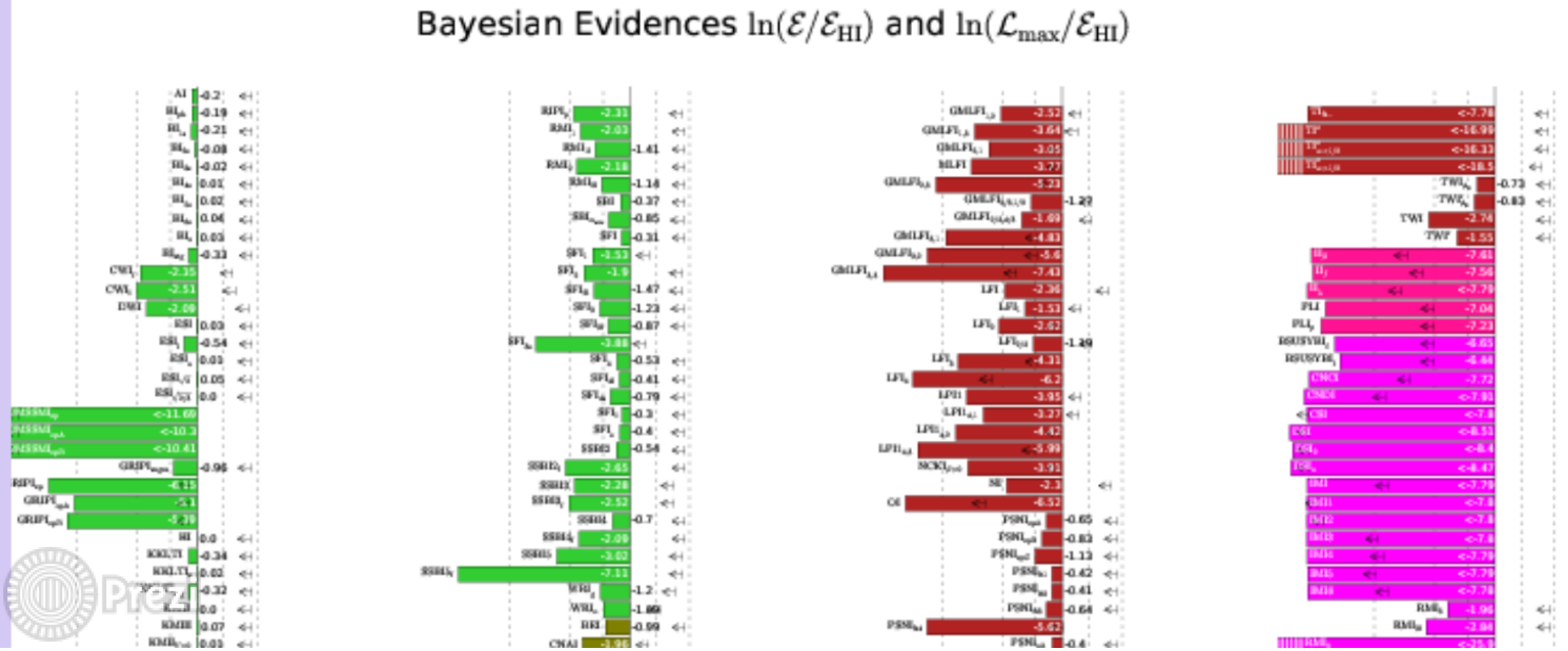
Explicit realizations in string theory, and multi-field aspects?

The Best Inflationary Models After Planck

Jerome Martin, Christophe Ringeval, Roberto Trotta, Vincent Vennin

(Submitted on 12 Dec 2013 (v1), last revised 3 Jun 2014 (this version, v3))

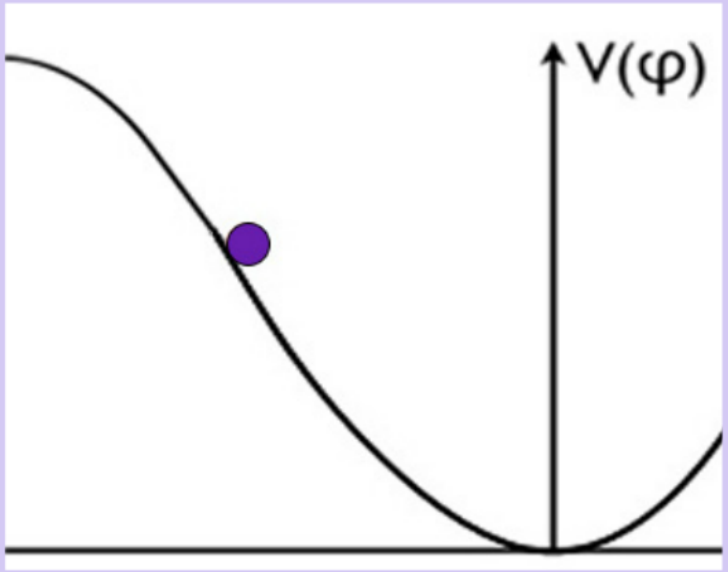
We compute the Bayesian evidence and complexity of 193 slow-roll single-field models of inflation using the Planck 2013 Cosmic Microwave Background data, with the aim of establishing which models are favoured from a Bayesian perspective. Our calculations employ a new numerical pipeline interfacing an inflationary effective likelihood with the slow-roll library ASPIC and the nested sampling algorithm MULTINEST. The models considered represent a complete and systematic scan of the entire landscape of inflationary scenarios proposed so far. Our analysis singles out the most probable models (from an Occam's razor point of view) that are compatible with Planck data, while ruling out with very strong evidence 34% of the models considered. We identify 26% of the models that are favoured by the Bayesian evidence, corresponding to 15 different potential shapes. If the Bayesian complexity is included in the analysis, only 9% of the models are preferred, corresponding to only 9 different potential shapes. These shapes are all of the plateau type.



Plateau inflation

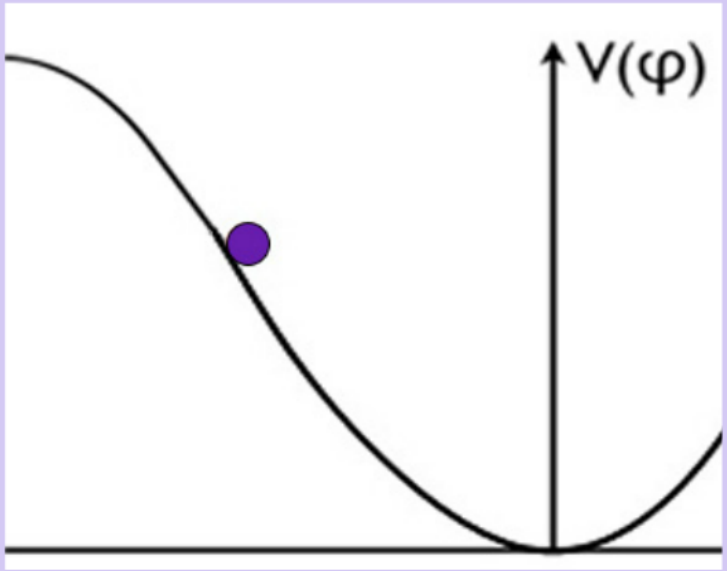
Planck is pointing towards plateau-like potentials:

$$-\frac{1}{2}(\partial\varphi)^2 - V(\varphi)$$



Plateau at infinite / finite distance, with (inverse) polynomial / exp fall-off.

Pole inflation



Redefinition to quadratic potential:

$$-\frac{1}{2}\left(\frac{\partial\varphi}{\partial\rho}\right)^2(\partial\rho)^2 - \frac{1}{2}m^2(\rho-\rho_0)^2$$

Plateau in potential implies a singularity in kinetic term! Only behaviour close to singularity is crucial.

[Galante, Kallosh, Linde, DR - PRL 2015]

Pole inflationary predictions

Behaviour at N=60 determined by leading pole in kinetic term:

$$\left(\frac{a_p}{\rho^p} + \dots\right)(\partial\rho)^2$$

Independent of subleading kinetic terms and fully independent of V: robustness of attractor!

$$n_s = 1 - \frac{p}{p-1}\frac{1}{N} \qquad r = \# \left(\frac{a_p}{N^p}\right)^{\frac{1}{p-1}}$$

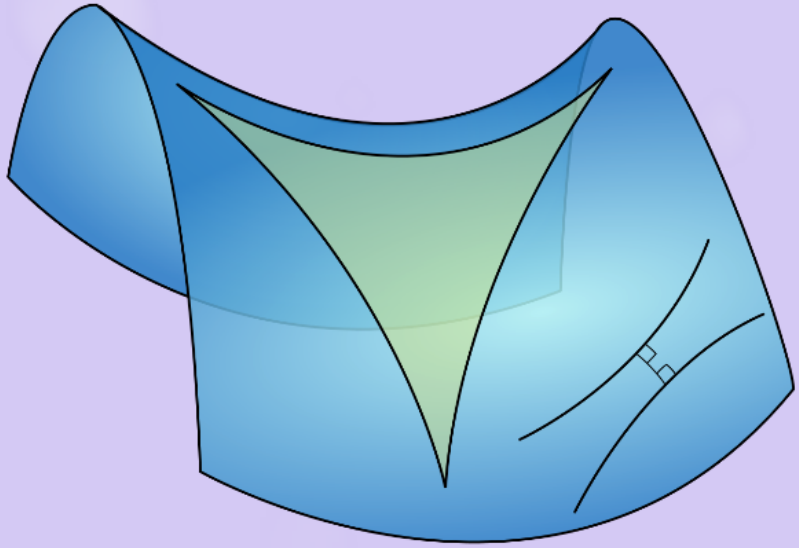
[Galante, Kallosh, Linde, DR - 2015]

Alpha-attractors

Planck data points towards p=2. Very special case: corresponds to hyperbolic geometry of moduli space

$$g_{ij}(\phi)(\partial\phi^i)(\partial\phi^j)$$

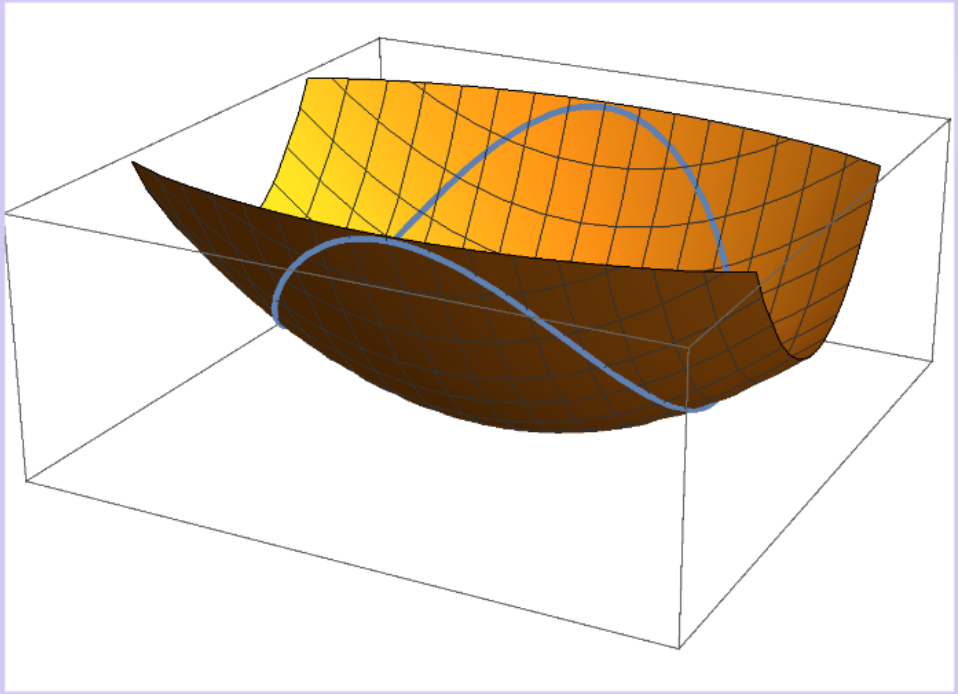
$$\frac{1}{1-\phi_i\phi^i/\alpha}\delta_{ij}$$

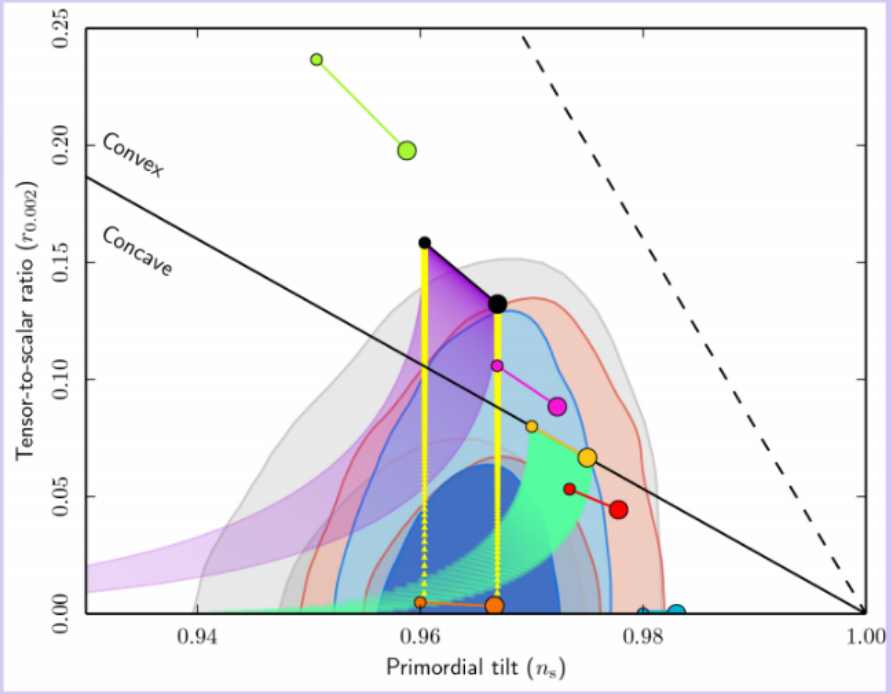


Single parameter: curvature alpha

[Kallosh, Linde, DR - 2013]

Alpha-attractors



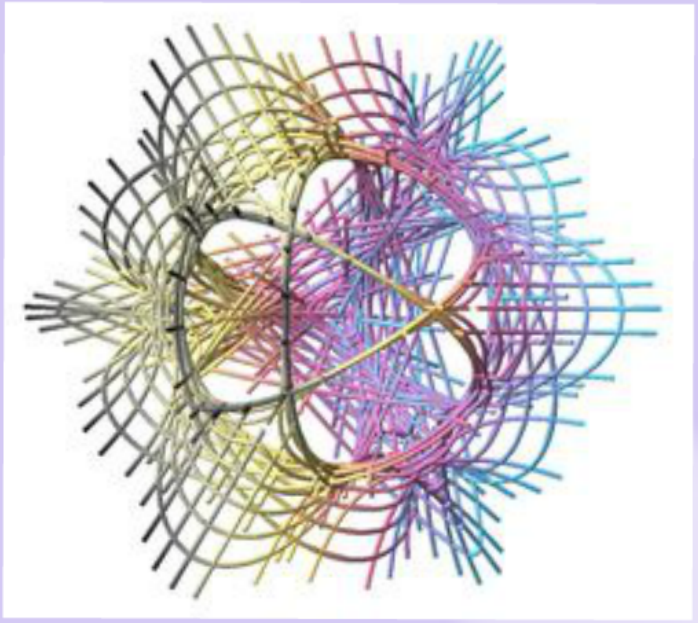


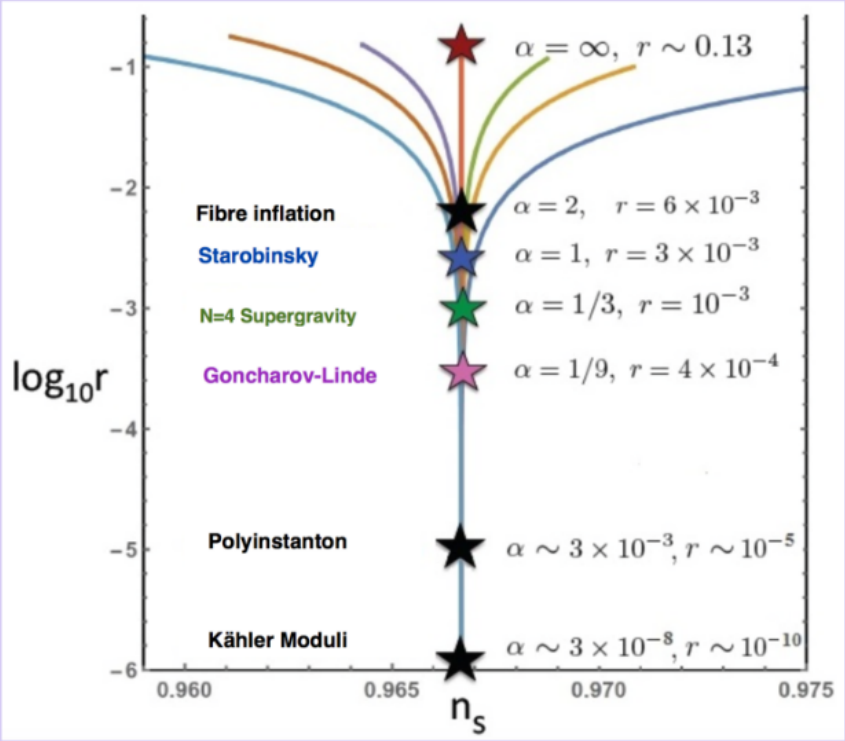
Robust predictions: $n_s = 1 - \frac{2}{N}$ $r = \frac{12\alpha}{N^2}$

[Kallosh, Linde, DR - 2013]

String theory

Hyperbolic moduli spaces very common in string compactifications. Fibre inflation leads to alpha = 2:





[Burgess, Cicoli, Quevedo 2016, Kallosh, Linde, DR, Westphal, Yamada 2017]

Multi-field effects?

Above results for single-field trajectories.

Possible to perform multi-field generalization in hyperbolic geometry?

- Inflation along a non-geodesic...
- Geometrical destabilization...

[Achucarro, Gong, Hardeman, Palma, Patil - 2010, Renaux-Petel, Turzynski - 2016]

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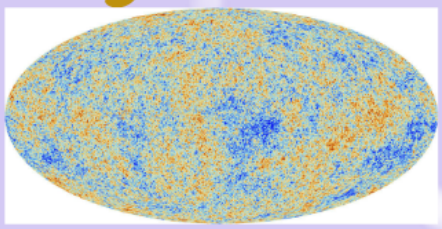
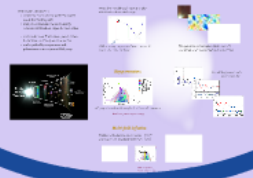
Inflation





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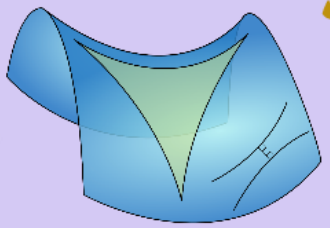

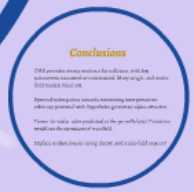

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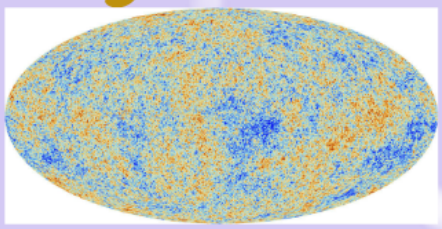

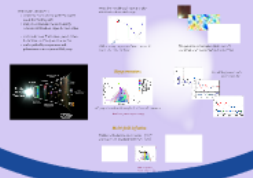

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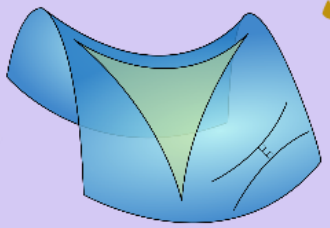

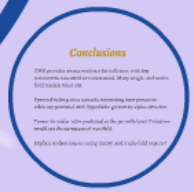

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