Attractor inflation beyond the poles

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arXiv:1903.03707

Lancaster–Manchester–Sheffield Consortium for Fundamental Physics

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PASCOS

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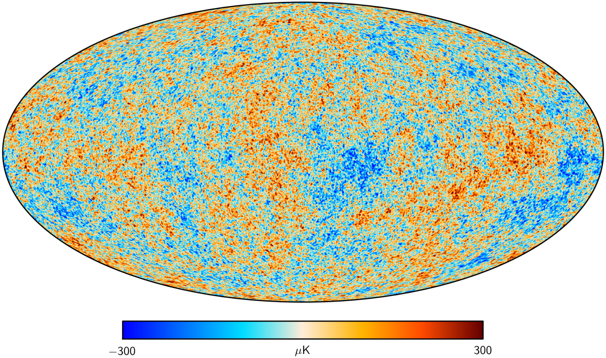
Outline

- Quick recap: inflation
- Stringy canonical models with singularities...
- ...beyond the poles

Why is the Universe the way it is?



2015, European Space Agency

- Why is the Universe so flat?
- Why is the CMB so homogeneous? (at scales larger than the horizon at the time of last scattering, $\approx 1.7^\circ$ in the sky)0

Inflation to the rescue

- Inflation solves the fine-tuning problems of standard Big Bang Cosmology...

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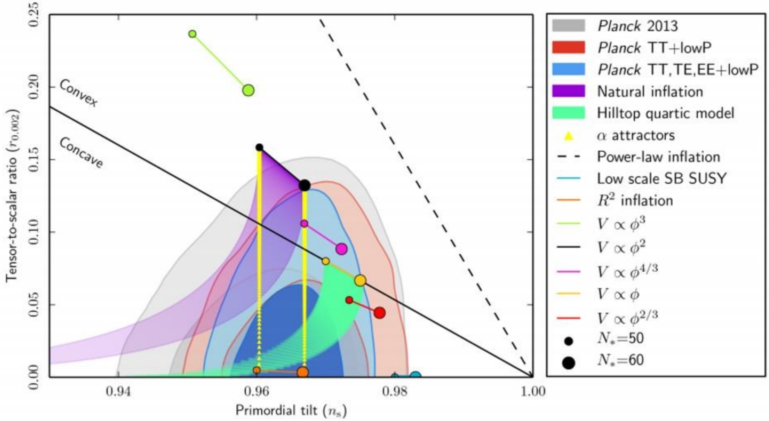
- Inflation solves the fine-tuning problems of standard Big Bang Cosmology...
- ...and then some:
  - Excellent *generic explanation* for the origin of anisotropies in the CMB from *primordial perturbations*
  - *Framework*, not *theory*: finding well-motivated models is tough...

Model after model after model...

- No definitive driving mechanism for inflation exists; numerous models (quintessence, modified gravity, string-inspired models...)
- Phenomenology of inflation reflected in CMB spectrum of anisotropies



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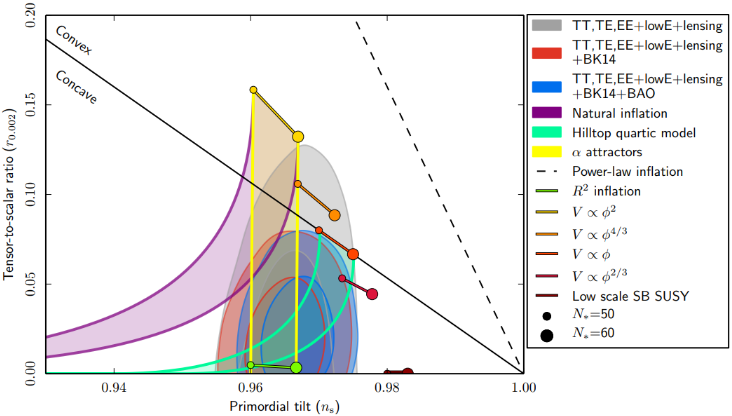

- Observations impose increasingly tighter constraints on inflation

α-attractors

- Originally motivated from spontaneously broken conformally invariant models [Kallosh, Linde, Roest (2013)]

- Can be realized in Kähler manifolds with negative curvature

  - At infinite moduli space distances, Kähler potential becomes

$$K = -3\alpha \ln(1 - \Phi\bar{\Phi}) \qquad \text{or} \qquad K = -3\alpha \ln(T + \bar{T})$$

  - Moduli space distance:

$$d\sigma^2 = \frac{3\alpha}{(1 - \Phi\bar{\Phi})^2} d\Phi d\bar{\Phi} = \frac{dr^2 + r^2 d\theta^2}{1 - \frac{r^2}{3\alpha}}$$

α-attractors

- Identify real part of saxion with inflaton: “phenomenologically” captured by following Lagrangian

$$(-g)^{-1/2}\mathcal{L} = -\frac{R}{2} + \frac{1}{2}\frac{(\partial_\mu \phi)(\partial^\mu \phi)}{\left(1 - \frac{\phi^2}{6\alpha}\right)^2} - V(\phi)$$

- Vast majority of studies studies focus on $\phi^2 < 6\alpha$, admitting a model with a canonical plateau (T-model, E-model, etc.)

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(beyond the poles)

Why go beyond?

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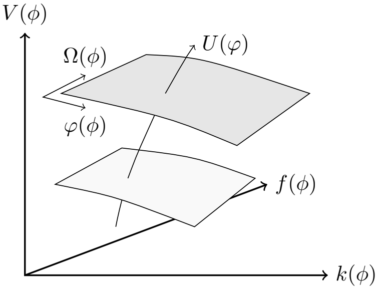
- α-attractors from $F(R)$ inflation, non-minimal couplings (ξ-attractors)...
- In a $\mathcal{N} = 1$supergravity embedding, may invert $T \to 1/T$
  - Corresponds to inflation as $\phi \to \infty$ [Scalisi, Valenzuela (2019)]
  - If saxion can evolve to infinity, how does this affect the overall phenomenology of the theory?

Frame equivalence classes



- Lagrangians linked via frame transformation $\mathcal{L} \sim \widetilde{\mathcal{L}}$ are *physically equivalent*

$$(-g)^{-1/2}\mathcal{L} = -\frac{f(\phi)}{2}R + \frac{k(\phi)}{2}(\partial\phi)^2 - V(\phi)$$

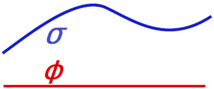
$$(-g)^{-1/2}\widetilde{\mathcal{L}} = -\frac{1}{2}R + \frac{1}{2}(\partial\sigma)^2 - U(\varphi)$$

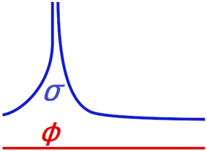
- Model space is quotient space of Lagrangian space

Theories with singularities

- Can't have pie (single chart) and eat it too (canonical chart): cannot canonicalise *without specifying interval*

$$\sigma(\phi) = \int_{\phi_0}^{\phi} \frac{d\phi'}{\left|1 - \frac{\phi^2}{6\alpha}\right|}$$





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- ...unless the string shoots off to infinity *at a single point*

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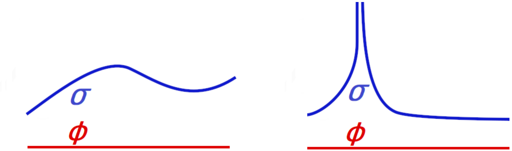

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Any theory with poles is a union of multiple canonical theories.

Attractor theories

- In pole inflation, observational features are strongly dependent on kinetic term features (order & residue) [Broy 2015 ,Terada 2016]

$$(-g)^{-1/2}\mathcal{L} = -\frac{R}{2} + \frac{\alpha_p}{2}\frac{(\partial_\mu\phi)(\partial^\mu\phi)}{|\phi-\phi_p|^p}(1+v_p\phi),$$

- Observables to lowest order are found (for $p > 1$)

$$n_{\mathcal{R}} = 1 - \frac{p}{(p-1)N}, \qquad r = \frac{8v_p^2}{\alpha_p}\left[\frac{\alpha_p}{(p-1)v_pN}\right]^{p/(p-1)}$$

Back to α-attractors

- Two poles of order $p = 2$: Lagrangian is

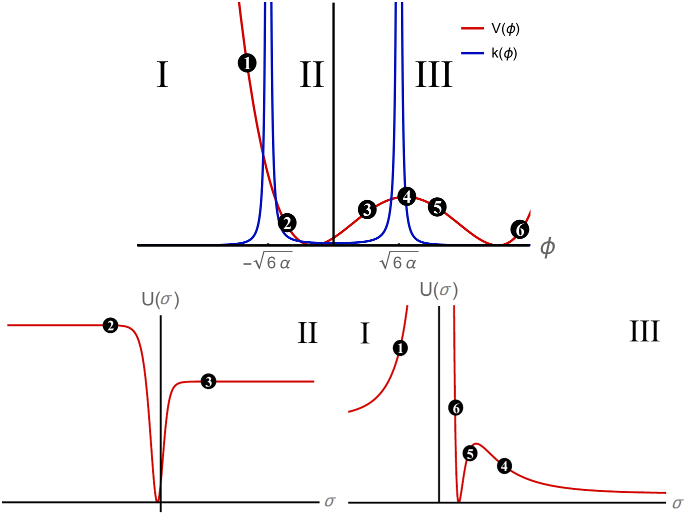
$$(-g)^{-1/2}\mathcal{L} = -\frac{1}{2}R + \frac{1}{2}\frac{(\partial_\mu\phi)(\partial^\mu\phi)}{\left(1-\frac{\phi^2}{6\alpha}\right)^2} - V(\phi)$$

- Usually, solve $\sigma'(\phi) = 1 - \phi^2/6\alpha$ to find $\sigma(\phi) = \sqrt{6\alpha}\tanh^{-1}(\phi/\sqrt{6\alpha})$

- In general, canonicalised field depends on arbitrary point ϕ_0

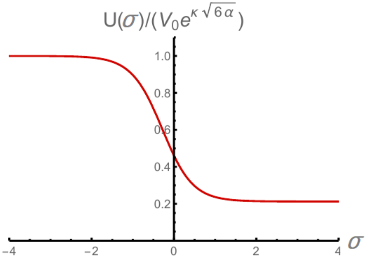
$$\sigma = \sqrt{\frac{3\alpha}{2}}\left(\ln\left|\frac{\phi+\sqrt{6\alpha}}{\phi-\sqrt{6\alpha}}\right| - \ln\left|\frac{\phi_0+\sqrt{6\alpha}}{\phi_0-\sqrt{6\alpha}}\right|\right)$$

Domains of α-attractors



Arbitrary non-canonical potential $V(\phi)$ and associated canonical potentials $U_{WTP}(\sigma)$ (domain II) and $U_{BTP}(\sigma)$ (I and III)

Quintessential inflation



- Quintessential inflation occurs with $V = V_0 e^{-\kappa\phi}$ within the poles:

$$U_{\rm in}(\sigma) = V_0 e^{-\kappa\sqrt{6\alpha}\,\tanh\left(\frac{\sigma}{\sqrt{6\alpha}}\right)}$$

- Observables for $\alpha \ll 1$:

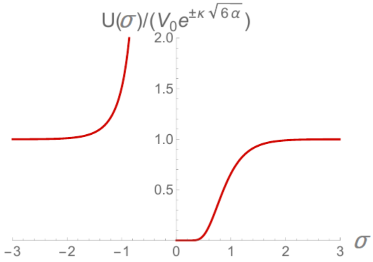
$$n_{\mathcal{R}} \approx 1 - \frac{2}{N} - \frac{\sqrt{3\alpha}}{N^2} - \frac{3\alpha(N-1)}{2N^3}$$

$$r \approx \frac{12\alpha}{N^2} - \frac{12\sqrt{3}\alpha^{3/2}}{N^3}$$

- Typical distance travelled is O(10), introducing tension with swampland distance conjecture (traversing large field distances implies infinite array of particles becoming exponentially light, invalidating EFT)

$$\Delta\sigma = \frac{1}{\mathcal{O}(1)}\frac{1}{H} \approx 10 \qquad \text{(from Planck 2018)}$$

Beyond the poles



- Beyond the poles $\phi < 0$ leads to eternal acceleration
- Beyond the poles $\phi > 0$ leads to inflation with predictions

$$n_{\mathcal{R}} \approx 1 - \frac{2}{N} + \frac{\sqrt{3\alpha}}{N^2} - \frac{3\alpha(N+1)}{2N^3}$$

$$r \approx \frac{12\alpha}{N^2} - \frac{12\sqrt{3}\alpha^{3/2}}{N^3}$$

- Distance travelled in field space is $\mathcal{O}(1)$; fares better in SDC

- ...but what exactly happens at $\sigma = 0$ ($\phi = \infty$)?

The edge of the field space?

- Inflation on projective ray
- Theory is *incomplete*: does not tell us what happens at the edge of the manifold
- Must impose boundary condition at “point at infinity”, analytically continuing potential (if 0, inflaton completely decouples or “escapes”, e.g. if matter coupling is $\propto \sigma^2\chi^2$ as opposed to usual $\phi^2\chi^2$)
- No single EFT valid over entire moduli space: EFT within or EFT beyond?

Conclusions

- Single-field models are a collection of canonical models with different predictions
- Supergravity embedding can lead to observationally viable inflation beyond the poles...
- ...but requires analytic extension to determine the late-time fate of the inflaton

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- Single-field models are a collection of canonical models with different predictions
- Supergravity embedding can lead to observationally viable inflation beyond the poles...
- ...but requires analytic extension to determine the late-time fate of the inflaton
- Initial conditions?
  - Arguments for favourable field values (e.g. starting on plateau) apply only to canonical models
  - Therefore, need new arguments for selecting a domain to inflate in
  - Distribution depends on which Lagrangian is in a sense more “fundamental”