String Phenomenology 2015

Evading The Weak Gravity Conjecture With F-Term Winding Inflation?

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based on `arXiv:1503.07912` with
Arthur Hebecker, Patrick Mangat and Fabrizio Rompineve

Introduction

- Realising **large-field inflation** in string theory is a theoretical challenge.
- Take axion(-like particle) as inflaton candidate.
  The inflaton potential can then be generated by

1) Non-perturbative effects

$$V = \Lambda^4 \left(1 - \cos\frac{\phi}{f}\right)$$

- ⊕ inflaton potential is naturally small
- ⊖ to realise large-field inflation need at least 2 axions
  [Kim, Nilles, Peoloso 2004]
- ⊖ further constrained / ruled out by recent no-go theorems

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2) Fluxes / Branes: Axion Monodromy

$$V = \mu^{4-p}\phi^p$$

[Silverstein, Westphal 2008; McAllister, Silverstein, Westphal 2008]
[Marchesano, Shiu, Uranga 2014; Blumenhagen, Plauschinn 2014; Hebecker, Kraus, LW 2014]

⊕ not affected by recent no-go theorems

⊖ need to tune to be consistent with data / moduli stabilisation

[Blumenhagen, Herschmann, Plauschinn 14; Hebecker, Mangat, Rompineve, LW 14]

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  employs **fluxes** and **non-perturbative effects**

  → use fluxes to generate long transplanckian trajectory (= alignment)

  → inflaton potential arises from non-perturbative effects:
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Outline

1. **The model**
2. **Relation to No-Go-Theorems based on Weak-Gravity-Conjecture**

The Model

Consider complex structure (CS) moduli sector with Kähler- and superpotential:

$$\boxed{\begin{aligned} K &= K(z,\bar{z};\ u-\bar{u},\ v-\bar{v};\ e^{2\pi i v},\ e^{2\pi i u}) \\ W &= w(z) + f(z)(u - Nv) + g(z)e^{2\pi i v} + h(z)e^{2\pi i u} \end{aligned}}$$

Kähler potential:

- Denote 2 CS moduli by u, v . The remaining CS moduli are labelled by z .
- The moduli u, v will be stabilised at Large Complex Structure: $\mathrm{Im}(u, v) > 1$.

  Kähler potential is shift-symmetric in u, v with corrections of type $e^{2\pi i u}, e^{2\pi i v}$.
- We also require $|e^{2\pi i u}| \ll |e^{2\pi i v}| \ll 1$.

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Superpotential: $W = W_{GVW} = \int G_3 \wedge \Omega$

- Tree-level:
  fluxes generate (GVW) superpotential for CS moduli.

- Need to ensure that u, v only enter the superpotential as above.

- By choosing appropriate flux numbers large can ensure that $N \gg 1$.

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Moduli stabilisation:

- K and $w(z)+f(z)(u-Nv)$ stabilise all z and $\mathrm{Im}(u), \mathrm{Im}(v)$.

  Stabilise such that $|e^{2\pi i u}| \ll |e^{2\pi i v}| \ll 1$.

- $f(z)(u-Nv)$ stabilises the direction $\mathrm{Re}(u-Nv)$. see also [Ben-Dayan, Pedro, Westphal 14; Shiu, Staessens, Ye 15]

- terms $\sim e^{2\pi i v}$ gives rise to potential along orthogonal (inflaton) direction.

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Inflaton potential:

- need to include the backreaction of other moduli.
- Including the backreaction of complex structure moduli obtain:

$$V = e^{K} \lambda\, e^{-4\pi \mathrm{Im}(v)} \left(1 - \cos \frac{2\pi\phi}{f}\right) \quad \text{with} \quad f = \frac{\sqrt{K_{u\bar{u}}}N}{2} \sim \frac{N}{2\ \mathrm{Im}(u)}\ .$$

Obtain superplanckian field range for large enough N.

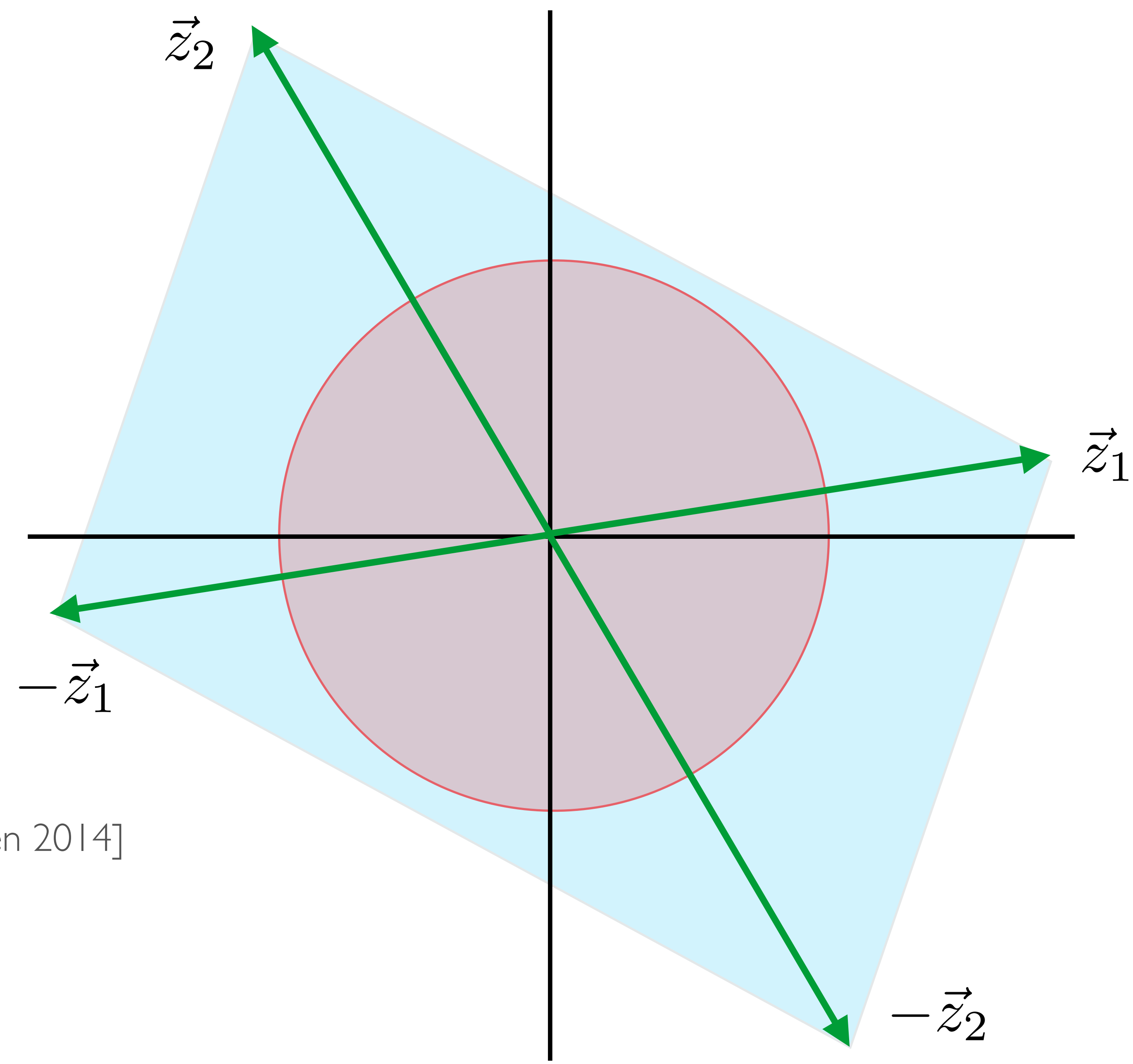
The Weak Gravity Conjecture

Weak gravity conjecture for axions: [Arkani-Hamed, Motl, Nicolis, Vafa 2006; Rudelius 2015; Brown, Cottrell, Shiu, Soler 2015]

- consider potential for multiple axions: $V = \sum_i \Lambda^4 e^{-m_i} \left(1 - \cos \vec{q}_i \cdot \vec{a}\right)$
- define "charge-to-mass-ratio" vectors:

$$\vec{z}_i = \frac{\vec{q}_i}{m_i}$$

- WGC satisfied if convex hull spanned by $\{\pm \vec{z}_i\}$ contains the unit sphere. [Cheung, Remmen 2014]



C_2 axion in type IIB: $r = 2/\sqrt{3}$
[Brown, Cottrell, Shiu, Soler 2015]

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- Turn off term $f(z)(u - Nv)$ at first.
- For now assume that u, v already have diagonal kinetic terms.
  (Straightforwardly generalised for general kinetic terms.)

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Schematically: $V \sim \Lambda^4 e^{-m}\left(1 - \cos\frac{\tilde{v}_1}{f_v}\right) + \Lambda^4 e^{-M}\left(1 - \cos\frac{\tilde{u}_1}{f_u}\right)$

- Here we defined $m \equiv 2\pi v_2$ and $M \equiv 2\pi u_2$
- and canonically normalised the axions u_1, v_1 .

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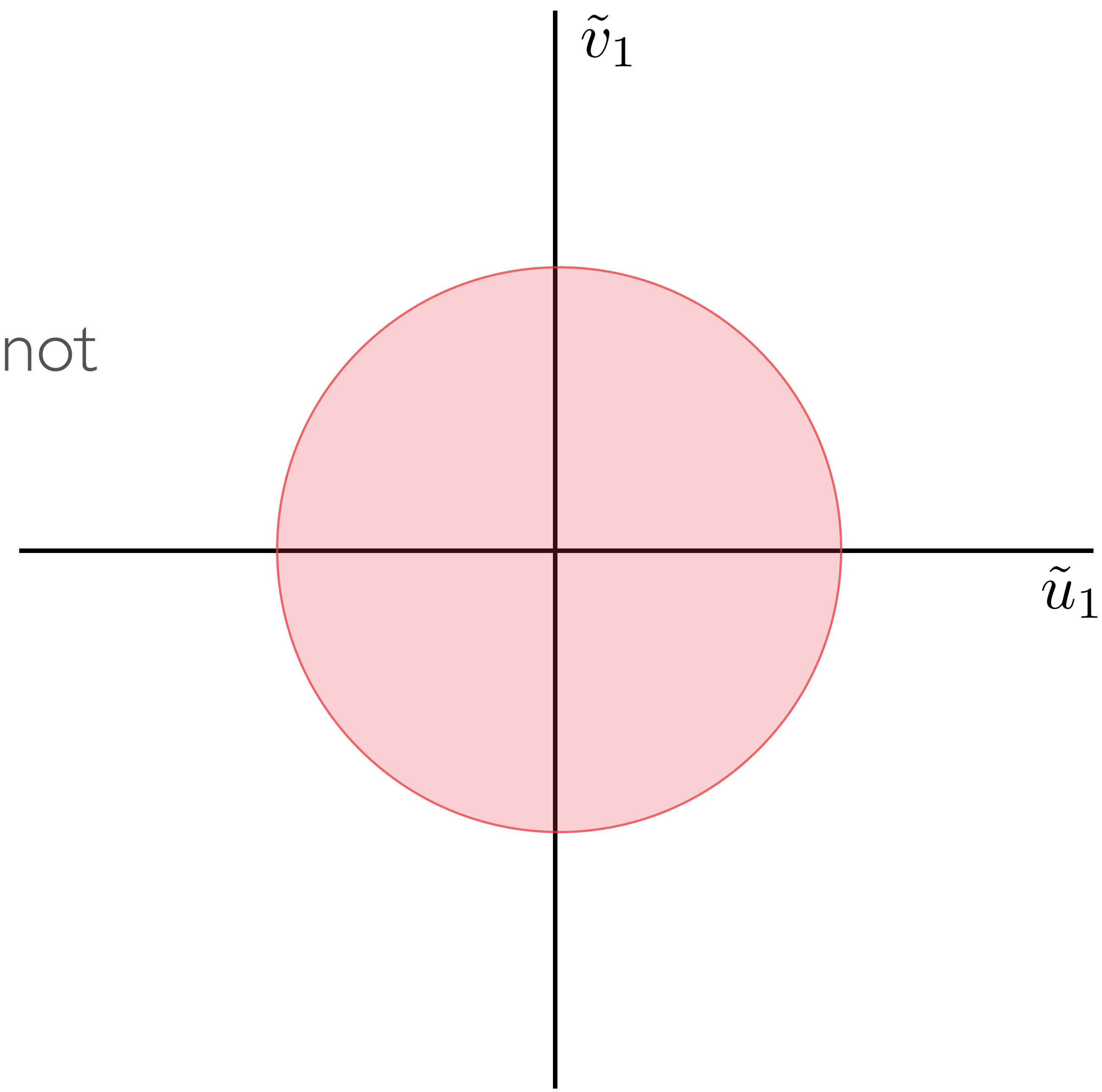
- Start with setup which satisfies the WGC.
- E.g., without alignment cannot obtain parametrically large axion field ranges.



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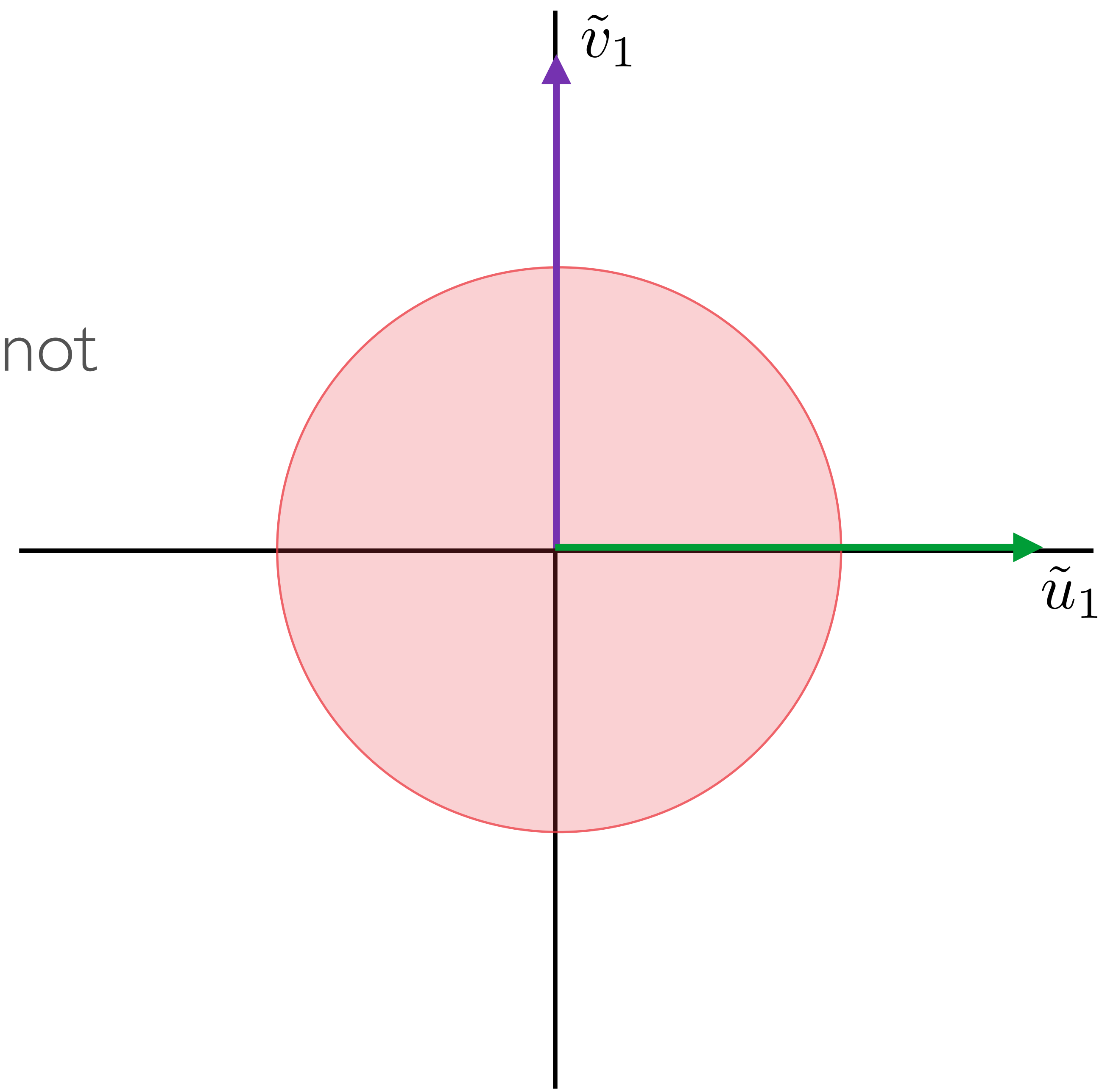

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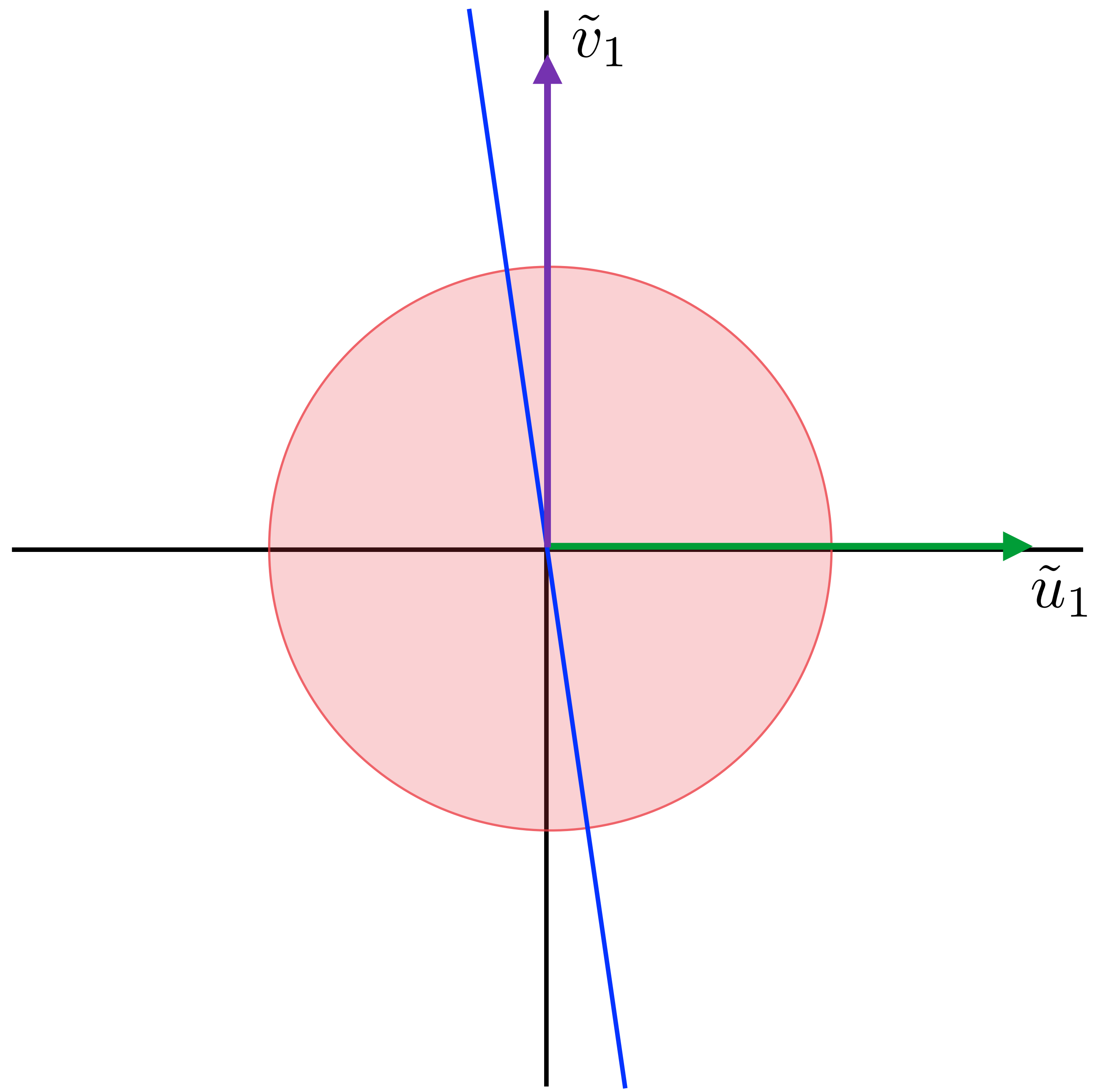
$$(u_1 - N v_1) = \text{const}$$

$$\Rightarrow v_1 = \frac{u_1}{N} + \text{const}$$



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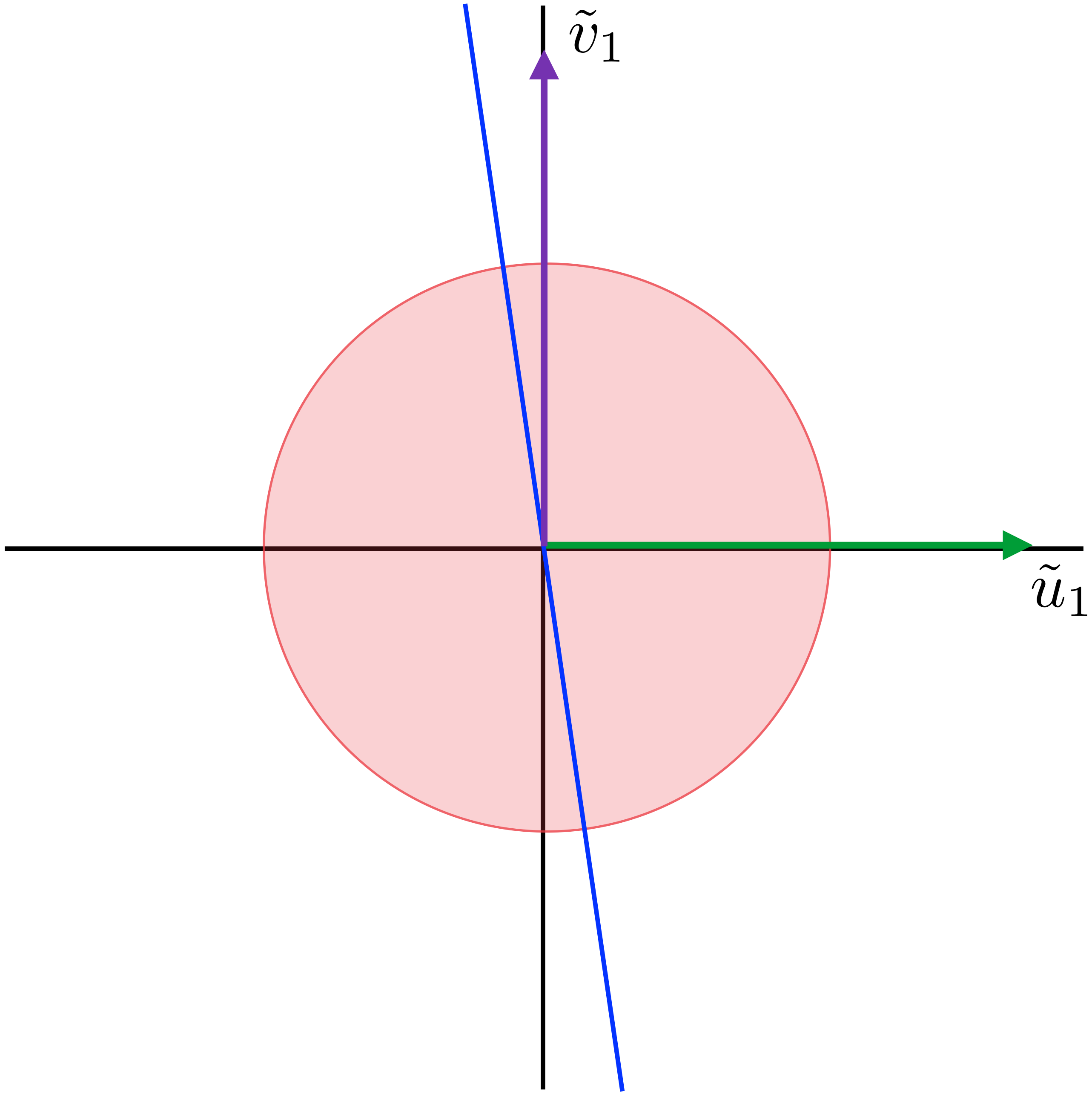

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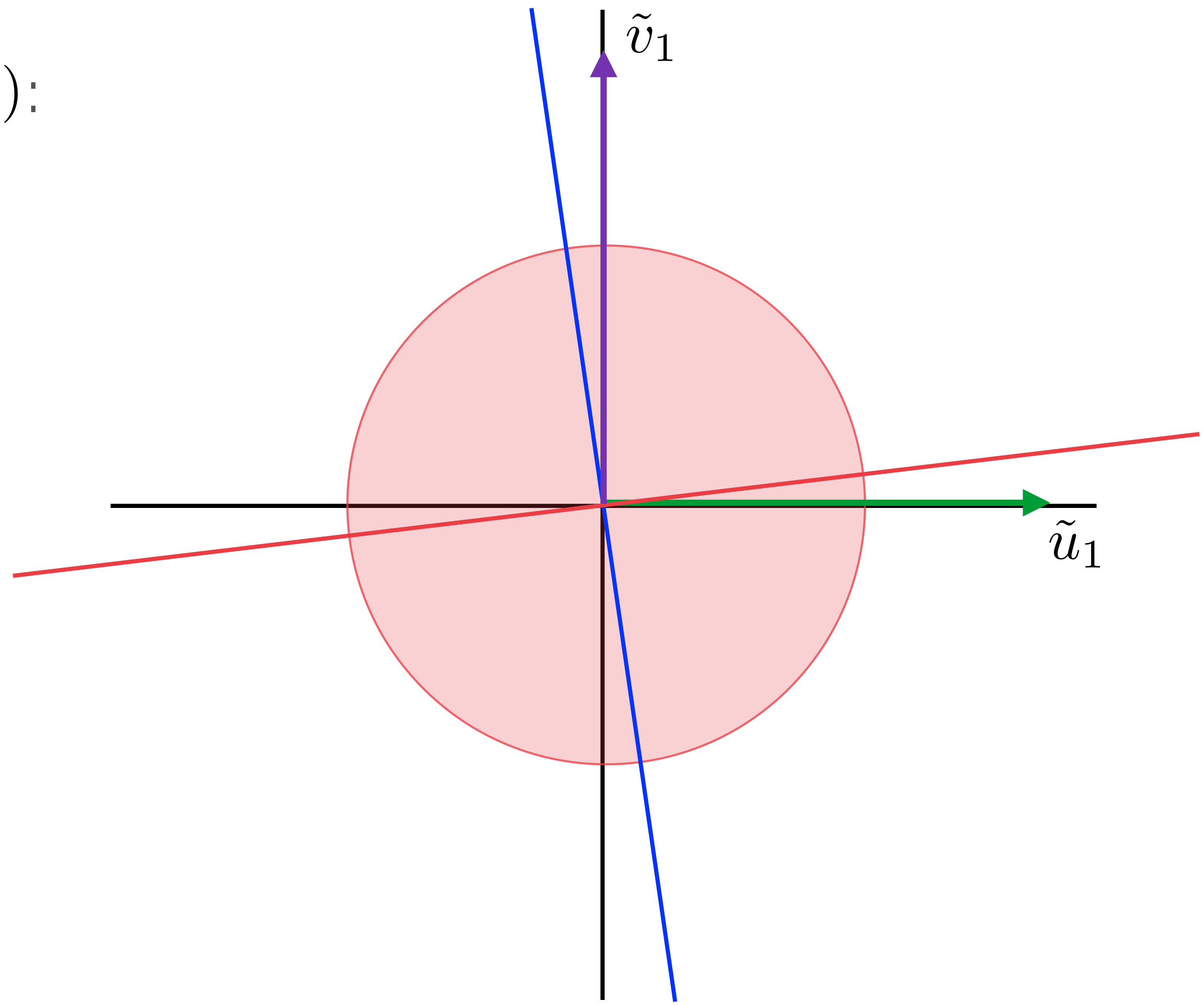
- Orthogonal direction

  = inflaton direction:

  $$\phi = \tilde{u}_1 + \mathcal{O}(1/N)$$



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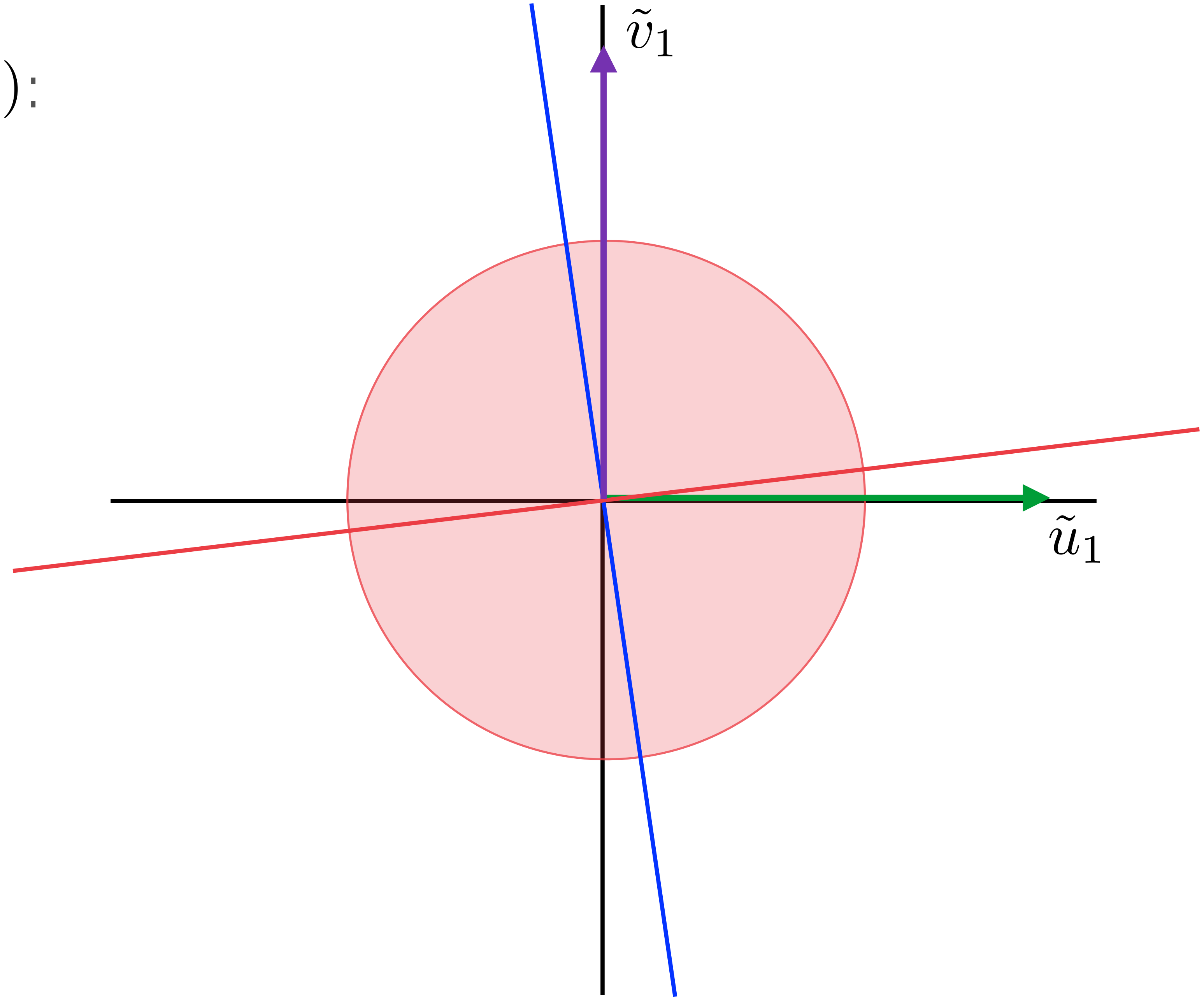

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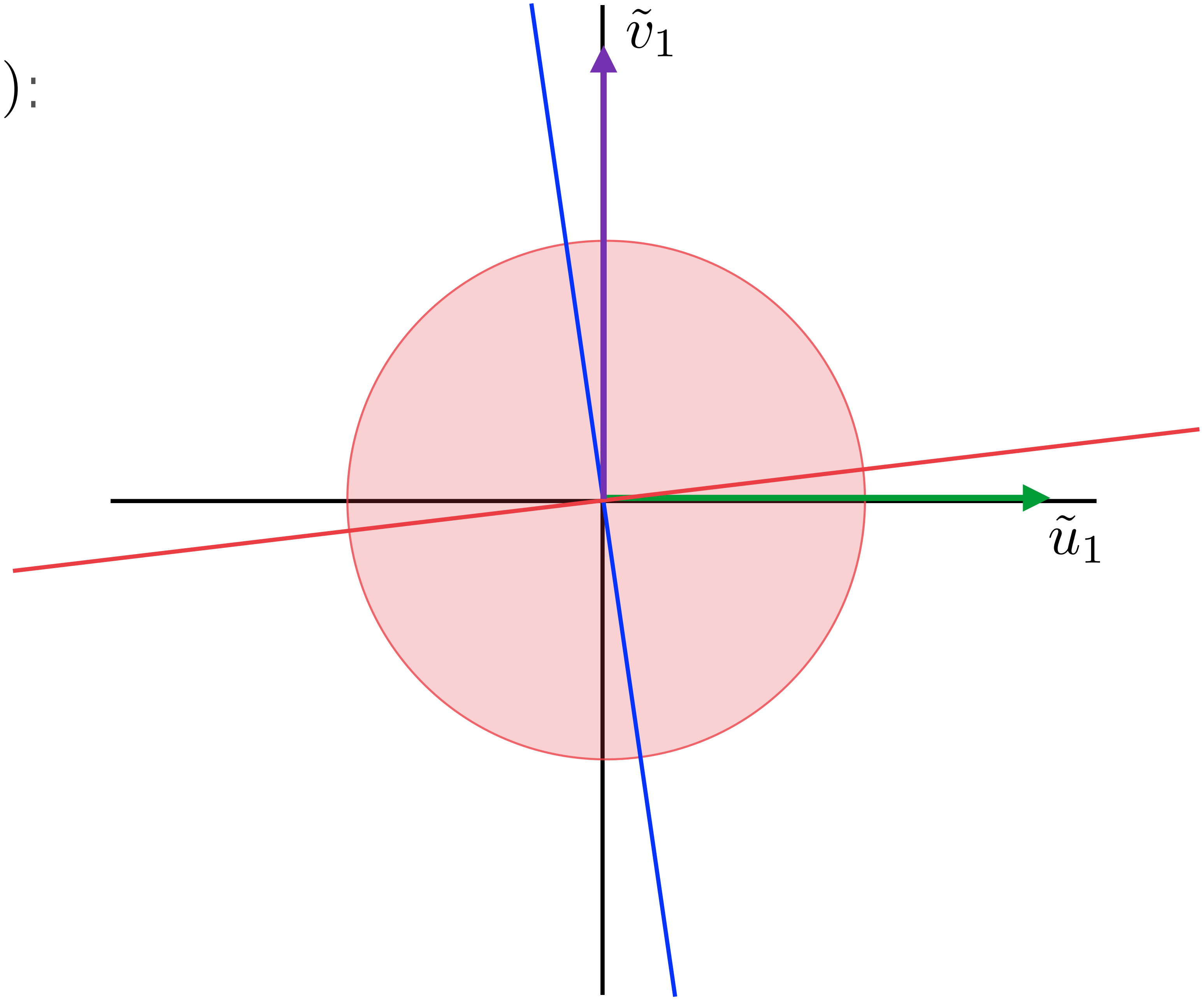

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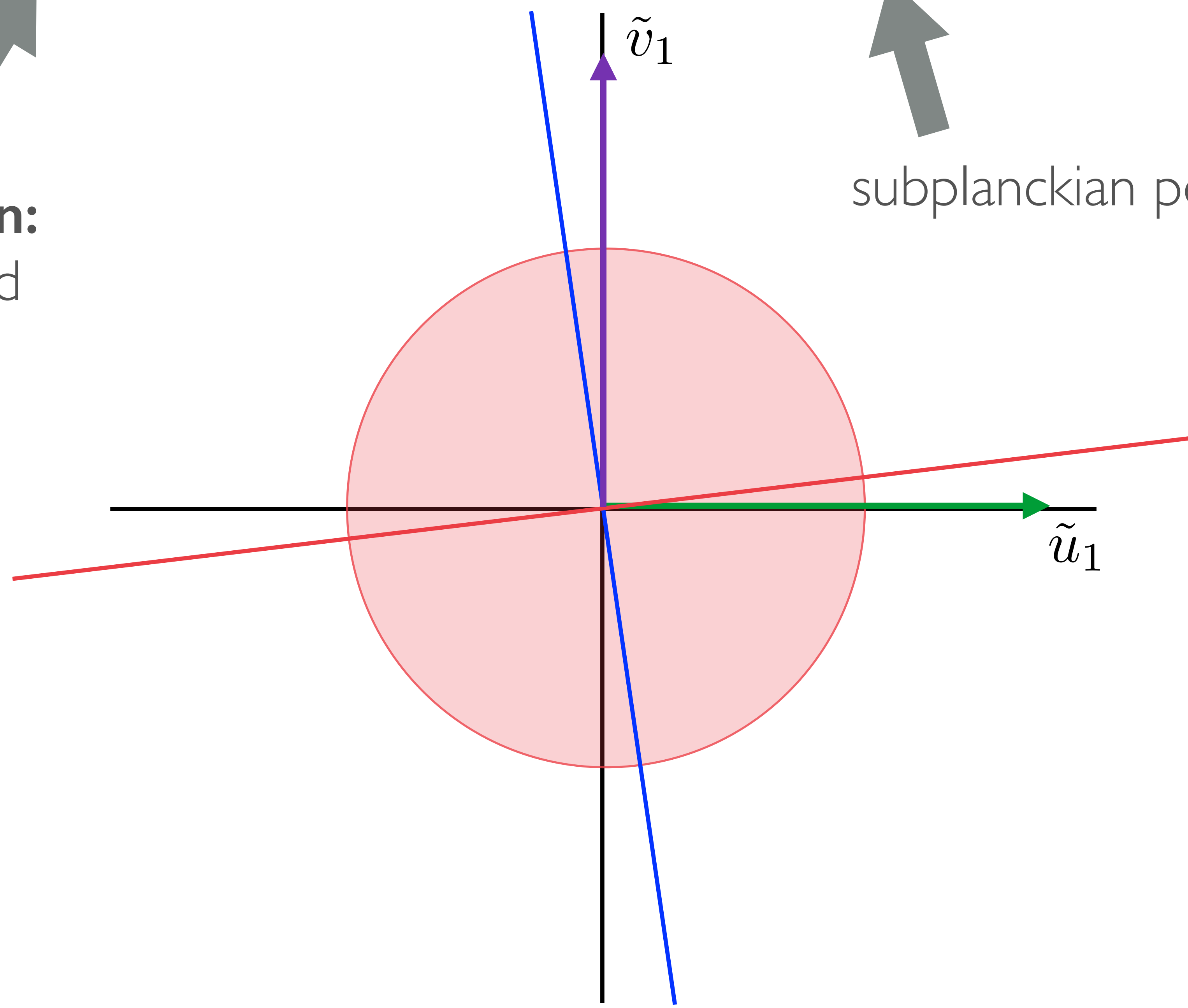
suitable for inflation:
transplanckian period

subplanckian period



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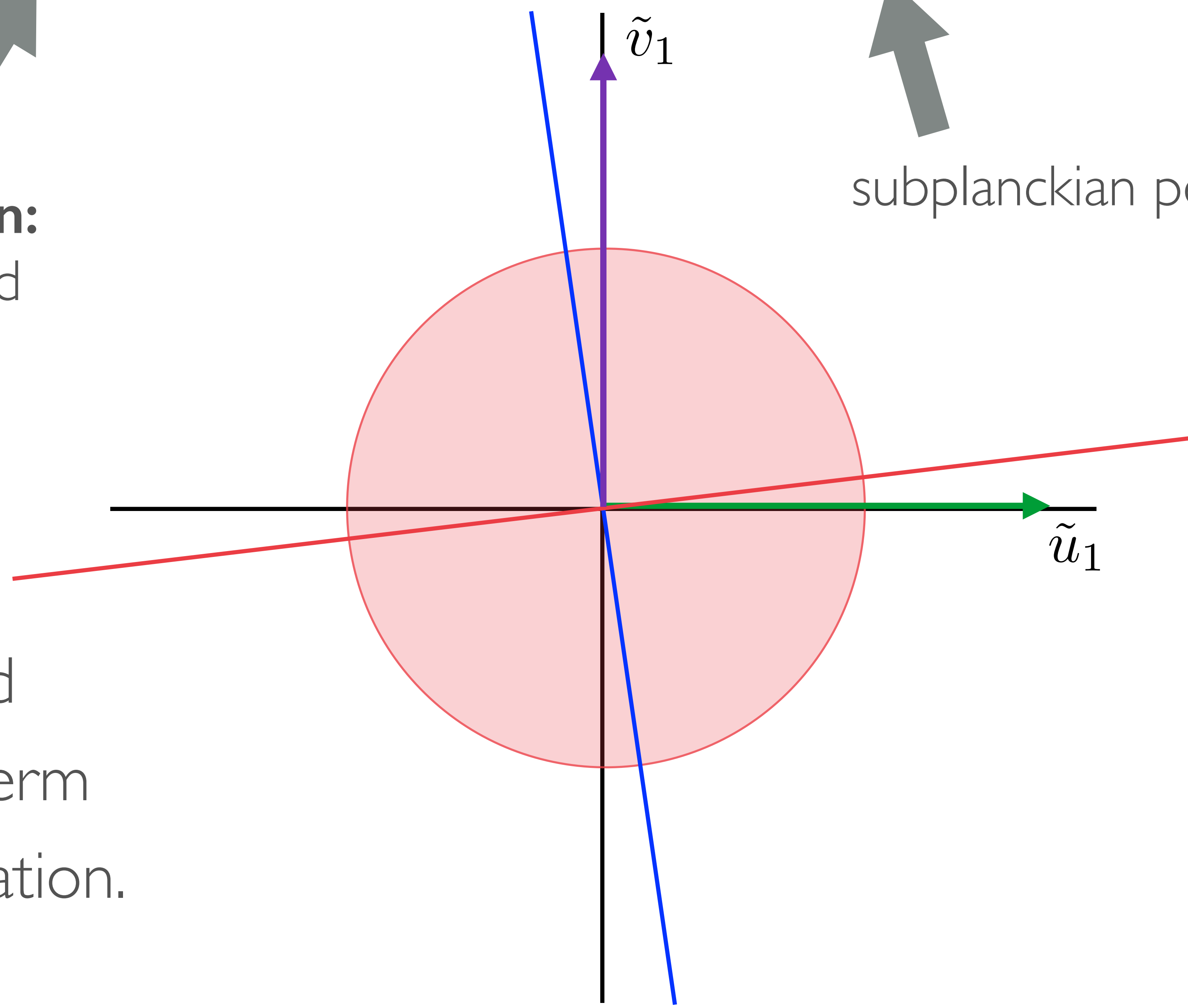

- As $M > m$ the 2nd term is suppressed compared to the 1st term and does not spoil inflation.

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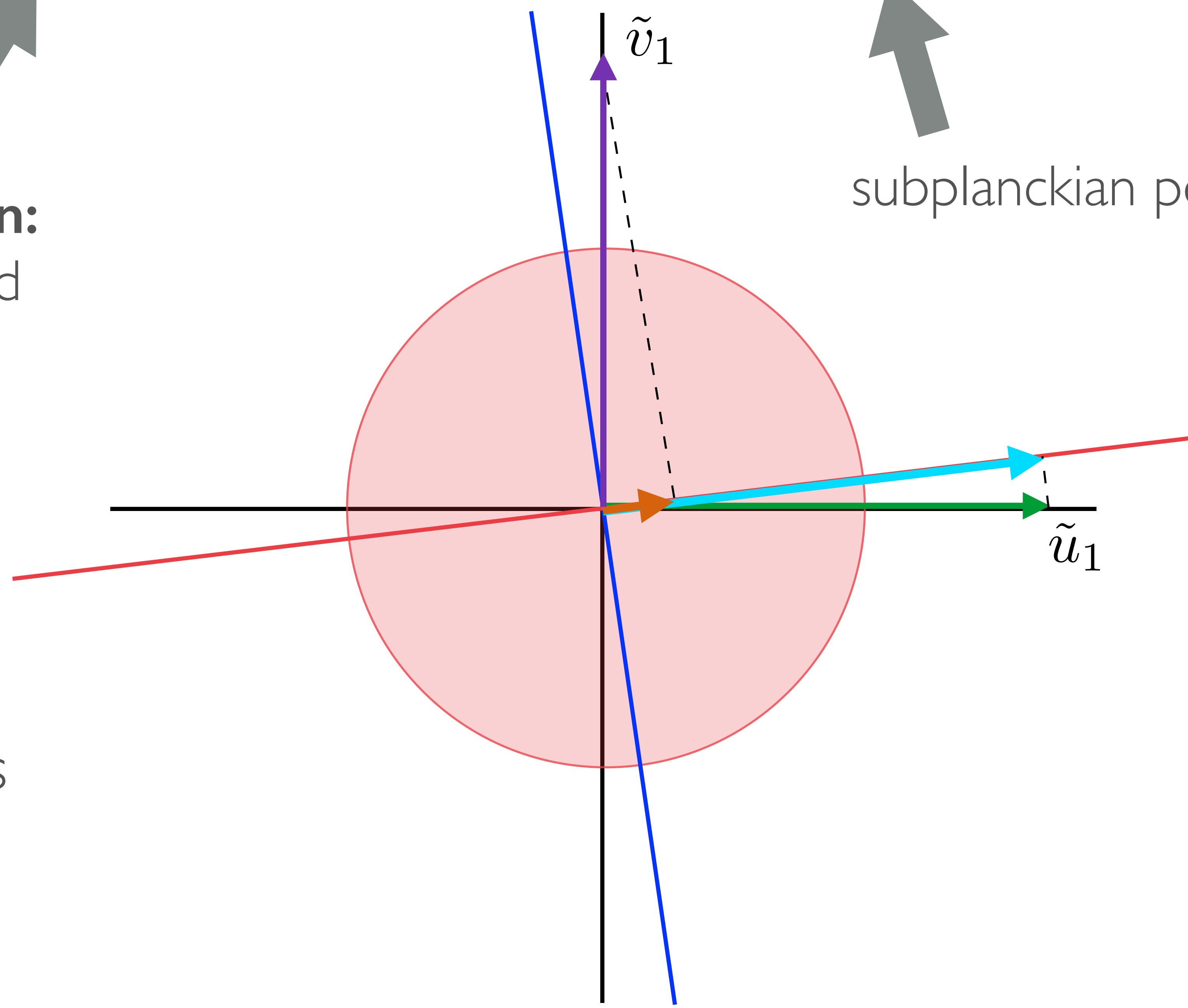

- Graphically:
  Projection of original charge-to-mass vectors onto inflaton direction.

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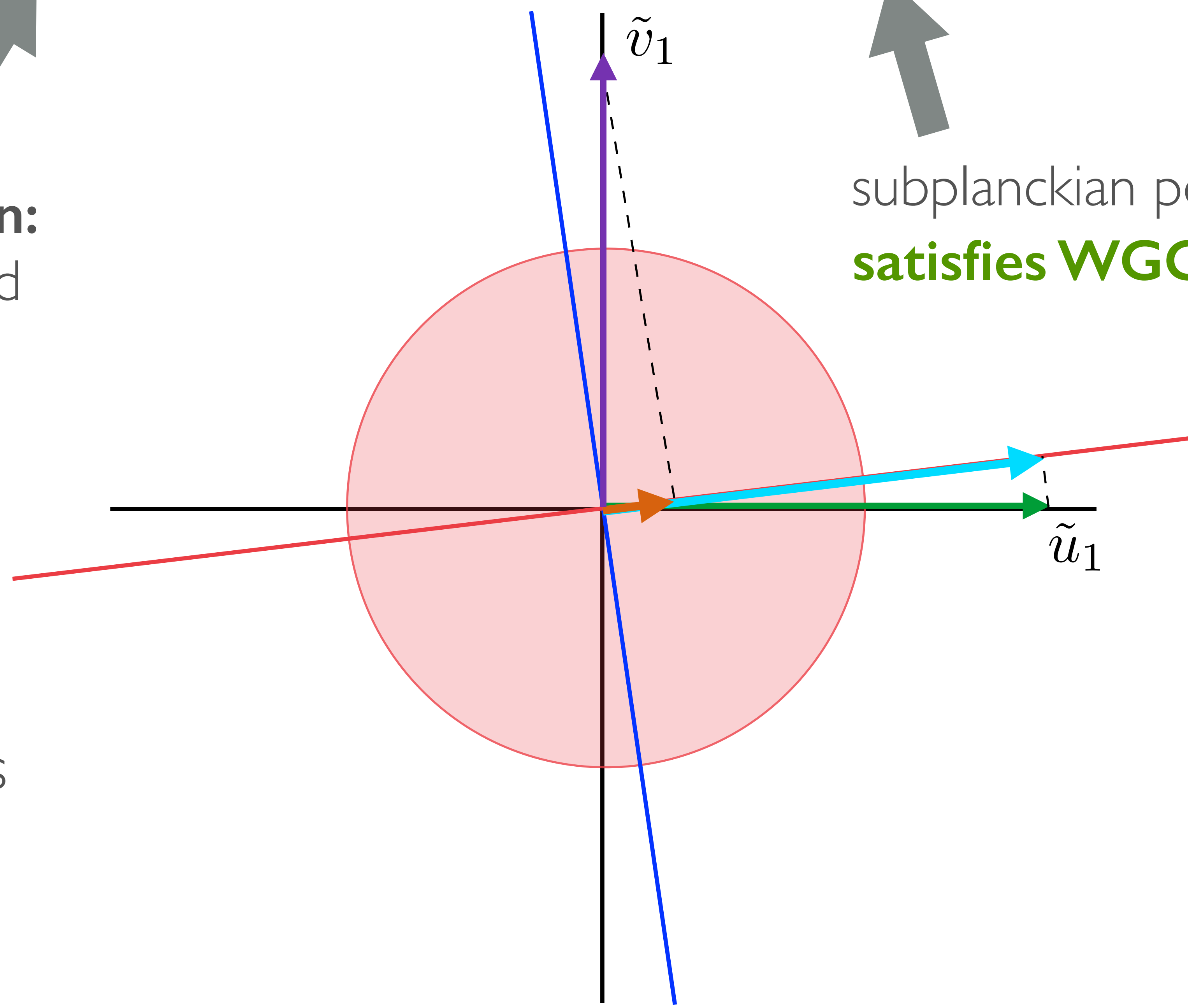

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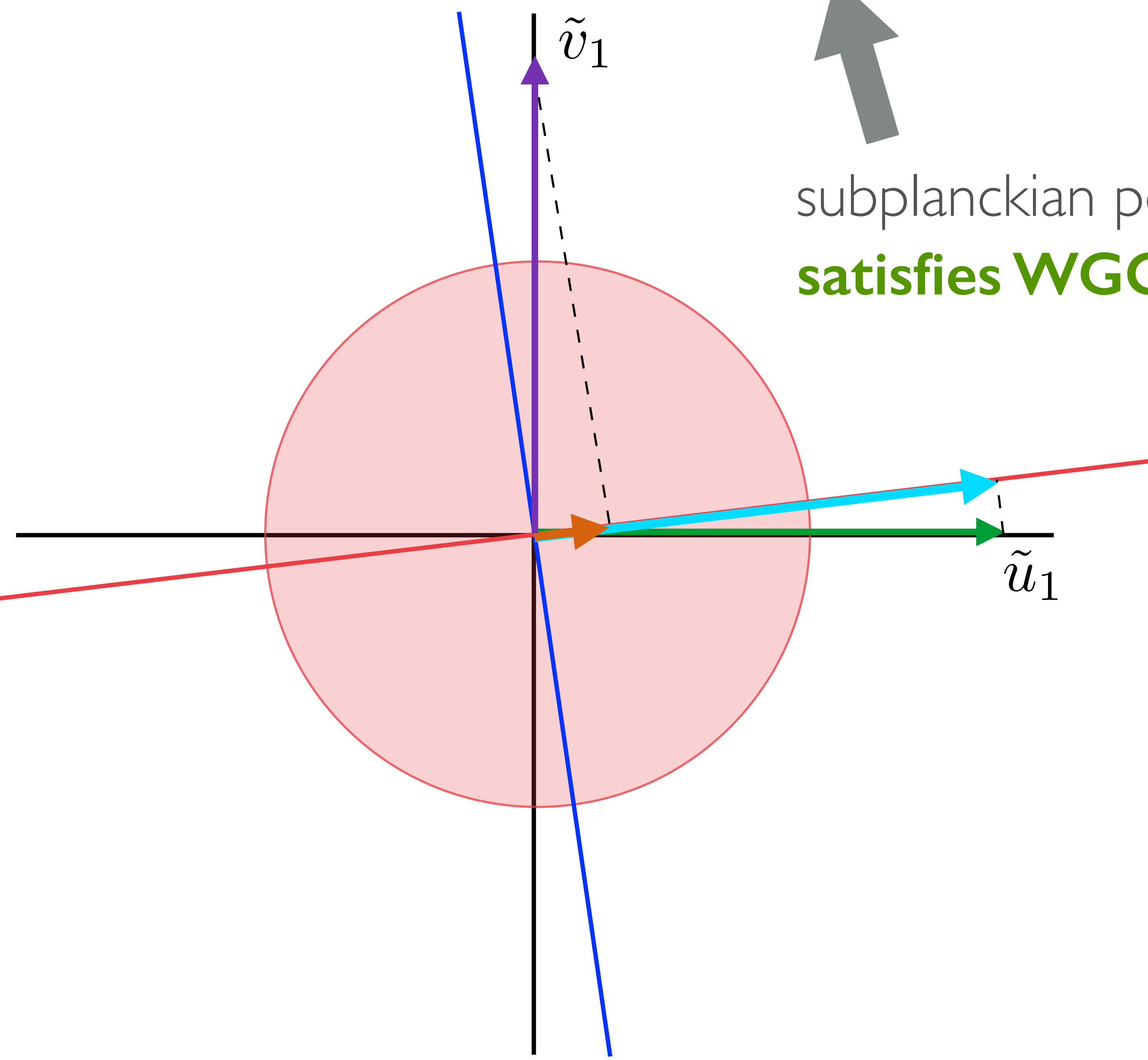

- Satisfy **mild WGC**: WGC satisfied, but not by "lightest" instanton as

$$M > m\,.$$

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Hierarchical axion inflation:

[Ben-Dayan, Pedro, Westphal 14]

Minimal setup: $W = \underbrace{A_1 e^{-a_1(T_u - NT_v)}}_{\text{fixes inflaton trajectory}} + A_2 e^{-a_2 T_v}$

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Extend: $W = \underline{A_1 e^{-a_1(T_u - NT_v)}} + A_2 e^{-a_2 T_v} + A_3 e^{-a_3 T_u}$

fixes inflaton trajectory

Need to stabilise moduli such that $|A_1 e^{-a_1(T_u - NT_v)}| > |A_2 e^{-a_2 T_v}| > |A_3 e^{-a_3 T_u}|$.

Conclusions

- We constructed a model of "natural inflation" in the complex structure moduli sector of a Calabi-Yau 3-fold.
- The generation of the flat direction (alignment), the stabilisation of saxions and the generation of the inflaton potential are to a certain degree independent of one another.
- Can be combined with Kähler moduli stabilisation according to the Large Volume Scenario. Backreaction? [Buchmüller, Dudas, Heurtier, Westphal, Wieck, Winkler 2014; Dudas, Wick 2015]
- The model is sufficiently explicit such that detailed quantitative questions can be addressed.
- Demonstrating the possibility of moduli stabilisation as required in an explicit model highly desirable.
- The model is consistent with the **mild form** of the WGC.