Moduli stabilization in flux compactifications

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+ To appear
with S. de Alwis, P. Martens

- Stabilizing moduli in the outer region: IIB and Heterotic flux compactifications
- Cosmological stability: A parachute for the “bat from hell”

Flux compactifications allow fine tuning

- IIB
  - coupling & CS moduli fixed by fluxes
  - Kahler moduli (volume,…) not fixed
  - no scale model, SUSY broken

$$V_{SUGRA} = e^K \left(K^{i\bar{j}} F_i F_{\bar{j}} - 3|W|^2\right)$$

$$W = 8\int_X G_3 \wedge \Omega$$

$$K = -\ln[-i(\tau - \bar{\tau})] - 3\ln(T + \bar{T}) - \ln\left(i\int_X \Omega \wedge \bar{\Omega}\right)$$

$$V = \int_X d^6 y \sqrt{\tilde{g}^{(6)}} \frac{e^{4\omega(y) - 12u(x)}}{24\tau_I} \left|iG_3 - \widetilde{*_6 G_3}\right|^2$$

$$G_3 = F_3 - \tau H_3$$

$$\tau = C_0 + ie^{-\phi}$$

$$H = a\Omega + b^\alpha \chi_\alpha + \bar{a}\bar{\Omega} + \bar{b}^{\bar{\beta}} \bar{\chi}_{\bar{\beta}}$$

$$v \equiv i\int \Omega \wedge \bar{\Omega}$$

→ $$iG_3 = *_6 G_3$$

Flux compactifications allow fine tuning

- Heterotic (on Kahler manifolds)
  - coupling & CS moduli fixed by fluxes + np effects
  - Kahler moduli (Volume, …) not fixed
  - No scale model, SUSY broken

$$H = a\Omega + b^{\alpha}\chi_{\alpha} + \overline{a}\overline{\Omega} + \overline{b}^{\overline{\beta}}\overline{\chi}_{\overline{\beta}}$$

$$v \equiv i \int \Omega \wedge \overline{\Omega}$$

$$W_{flux} = \frac{4}{\alpha'^4} \int H \wedge \Omega = +\frac{4i}{\alpha'^4}\overline{a}v$$

$$\int_M H \wedge \Omega \approx \sum K_{A_i} \int_{B_i} \Omega$$

$$W_{np} = -C(G)\mu^3 e^{-\frac{8\pi^2}{C(G)}S-1}$$

$$W_{tot} = W_{flux} + W_{np}$$

$$K = -\ln(S+\overline{S}) - 3\ln(T+\overline{T}) - \ln\left(\frac{v}{4\alpha'^3}\right)$$

$$V_{SUGRA} = e^K \left(K^{i\bar{j}} F_i F_{\bar{j}} - 3|W|^2 \right)$$

$$V_{SUGRA} = \frac{\alpha'^4}{32 T_R^3 S_R v} \left\{ \left| \frac{4i}{\alpha'^4} \bar{a} v + \left(1 + \frac{16\pi^2}{C(G)} S_R \right) W_{np} \right|^2 + G^{\alpha\bar{\beta}} \left(\frac{4i}{\alpha'} b^{\bar{\gamma}} G_{\alpha\bar{\gamma}} v + \partial_\alpha K W_{np} \right) \left(\frac{4i}{\alpha'} b^{\bar{\beta}} G_{\delta\bar{\beta}} v + \partial_{\bar{\beta}} K W_{np} \right) \right\}$$

$$G_{\alpha\bar{\beta}} = -\frac{i}{v} \int \chi_\alpha \wedge \chi_{\bar{\beta}}$$

complex structure moduli & coupling fixed by generic fluxes & gaugino-condensation

$$\frac{4i}{\alpha'^4} \bar{a} v - \frac{C(G)}{32\pi^2 \alpha'^{3/2}} \left(1 + \frac{16\pi^2}{C(G)} S_R \right) e^{-\left[\left(\frac{8\pi^2}{C(G)}\right) S + 1\right]} = 0$$

$$\partial_\alpha K = \alpha'^3 \left(1 + (16\pi^2 / C(G)) S_R \right) \frac{b_\alpha}{\bar{a}}$$

Small *av* ➔ Weak coupling (S_R > a few)
Search in the discretuum
(similar to the IIB case - GKP)

$$H = a\Omega + b^\alpha \chi_\alpha + \bar{a}\bar{\Omega} + \bar{b}^{\bar{\beta}} \chi_{\bar{\beta}}$$

$$v \equiv i \int \Omega \wedge \bar{\Omega}$$

Fixing the rest of the moduli: Revival of race-track models

- IIB: Fluxes, multiple gaugino-condensates*
  (no need for Dbar)
- Generic problem: runaway potentials

  - ***Importance of the central region***

EXAMPLE:

$$W = c + \sum d_i e^{-8\pi^2 T/C(G_i)}$$

* On D7's + discrete Wilson lines
Multi brane-instantons wrapping cycles (??)

$$c \equiv W_0$$

Fixing the rest of the moduli: Revival of race-track models

- Heterotic: Fluxes, multiple gaugino-condensates + threshold corrections
- Generic problem: runaway potentials

$$W_{np} = -\sum_i C(G_i)\mu^3 e^{-\frac{8\pi^2}{C(G_i)}(S+\beta_i T)-1}$$

Eventually:
non-Kahler dual to IIB

Threshold corrections for orbifolds

$$W = c + \sum d_a e^{-3kS/2\beta_a} \; /\eta(T)^6$$

$$c = \int H \wedge \Omega$$

$$V = \frac{|\eta(T)|^{-12}}{2S_R(2T_R)^3}\left\{\left|2S_R\omega_S - \omega - c\eta^6(T)\right|^2 + 3\left|\frac{T_R}{\pi}\widehat{G}_2\omega + c\eta^6(T)\right|^2 - 3\left|\omega + c\eta^6(T)\right|^2\right\}$$

Moduli potentials: general considerations for IIB, HET, …

$$\varepsilon = m_{3/2}/M_{Pl}$$

- outer region stabilization
- F-term SUSY breaking — $F \sim O(\varepsilon)$
- small +ve or vanishing CC — $CC < O(\varepsilon^2)$
- stable minima

Steep potentials

$$\frac{\left|(T+\overline{T})\partial_T^{(n+1)} W\right|}{\left|\partial_T^n W\right|} \gg 1 \quad n = 0, 1, 2, 3$$

➔ tune 4 parameters

$$\frac{\left|(T+\overline{T})\partial_T^{(n+1)} W\right|}{\left|\partial_T^n W\right|} \not\gg 1 \quad n = 0, 1, 2, 3$$

Moduli potentials: Results

- **Single field**
- **Impossible with a non-negative CC (small negative o.k.)**

$$K = -A\ln(\Phi + \overline{\Phi}), \text{ for } 1 \leq A \leq 3$$

$$W = a0 + (a1_R + ia1_I)(\Phi_R + i\Phi_I - 1) + (a2_R + ia2_I)(\Phi_R + i\Phi_I - 1)^2$$

sufficient

show

$$\frac{\partial^2 V}{\partial\Phi_R\partial\Phi_R} + \frac{\partial^2 V}{\partial\Phi_I\partial\Phi_I} < 0$$

$$\frac{\partial^2 V}{\partial\Phi_R\partial\Phi_R} + \frac{\partial^2 V}{\partial\Phi_I\partial\Phi_I} = 4\frac{\partial^2 V}{\partial\Phi\partial\overline{\Phi}}$$

$$\left[\frac{\partial^2 V}{\partial\Phi\partial\overline{\Phi}}\right]_{|\Phi=1} = -2\epsilon$$

$$A = 3$$

$$\left[\frac{\partial^2 V}{\partial\Phi\partial\overline{\Phi}}\right]_{|\Phi=1} = -\frac{2^{3-A}}{A(3-A)}\Big[(3-A)a1_I^2 + (3+A)a1_R^2 + \sqrt{A}a1_R\sqrt{12a1_R^2 - (3-A)\left(2^A A\epsilon - 4a1_I^2\right)}\Big] \qquad A \neq 3$$

ε is the CC

Moduli potentials: Results

- **Two fields: some examples**, no general analysis
- More fields, has not been analyzed
- Strong dependence on the Kahler potential
- Additional near-by SUSY minima: Landscape within landscape

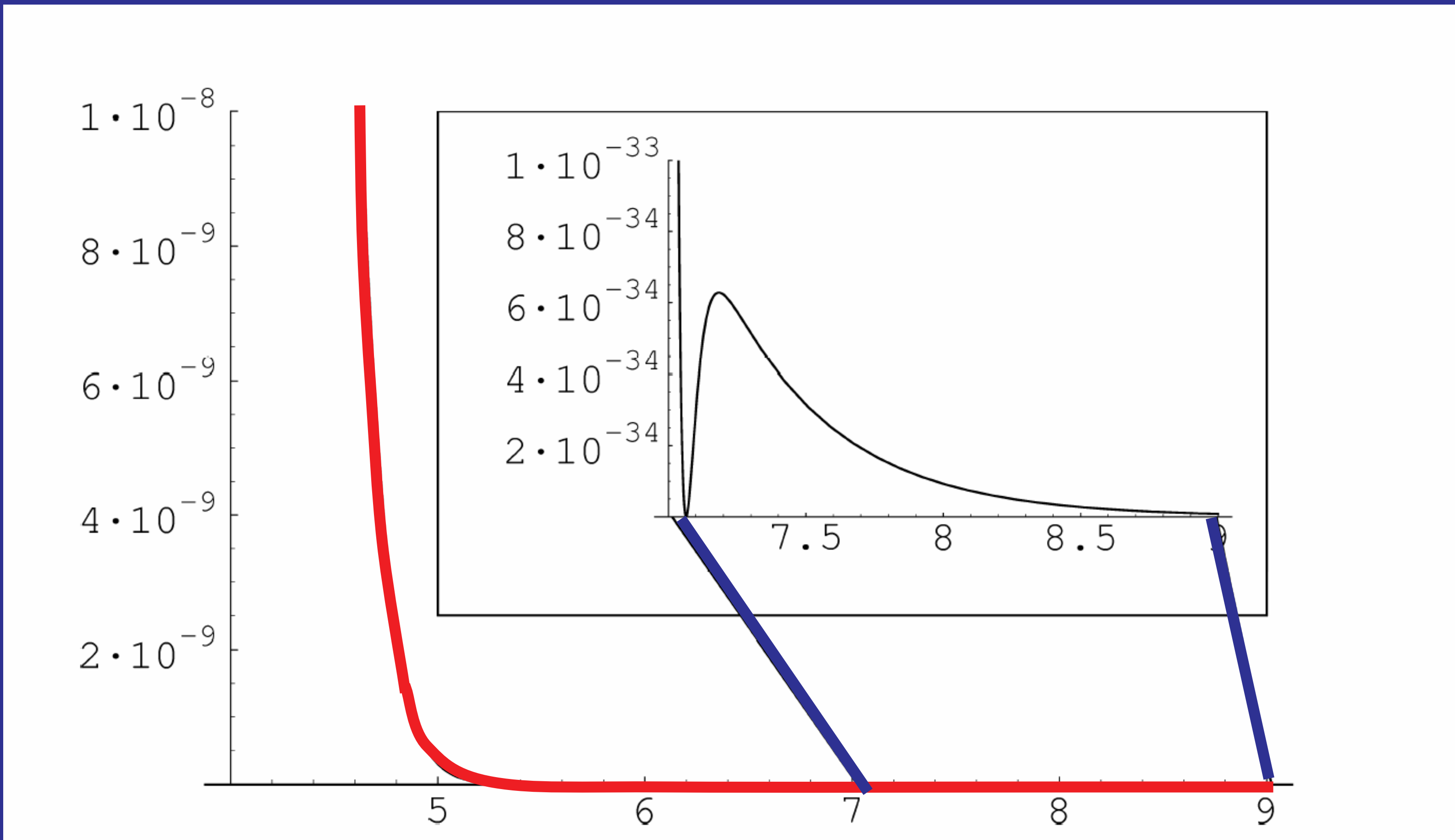
$$K = -\ln(S+\overline{S}) - 3\ln(T+\overline{T})$$

$$\begin{aligned} W &= a0 + a1(S_R + iS_I - 1) + a2_R(S_R + iS_I - 1)^2 + a3(S_R + iS_I - 1)^3 \\ &+ b1(T_R + iT_I - 1) + b2(T_R + iT_I - 1)^2 + b3(T_R + iT_I - 1)^3 \\ &+ ab1(S_R + iS_I - 1)(T_R + iT_I - 1) + ab2(S_R + iS_I - 1)(T_R + iT_I - 1)^2 \\ &+ ba2(S_R + iS_I - 1)^2(T_R + iT_I - 1). \end{aligned}$$

Examples: quartic & quadratic, islands, not particularly fine-tuned

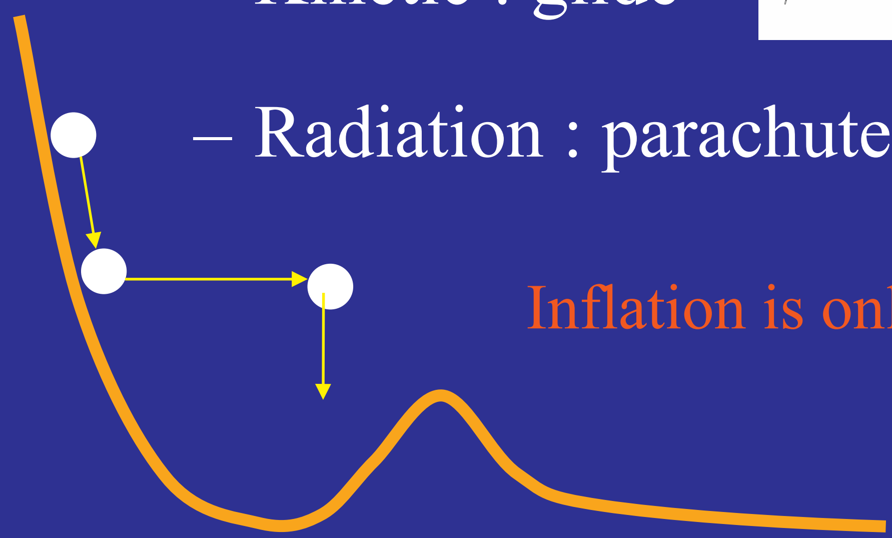
Cosmological stability

- The overshoot problem



Proposed resolution: role of other sources

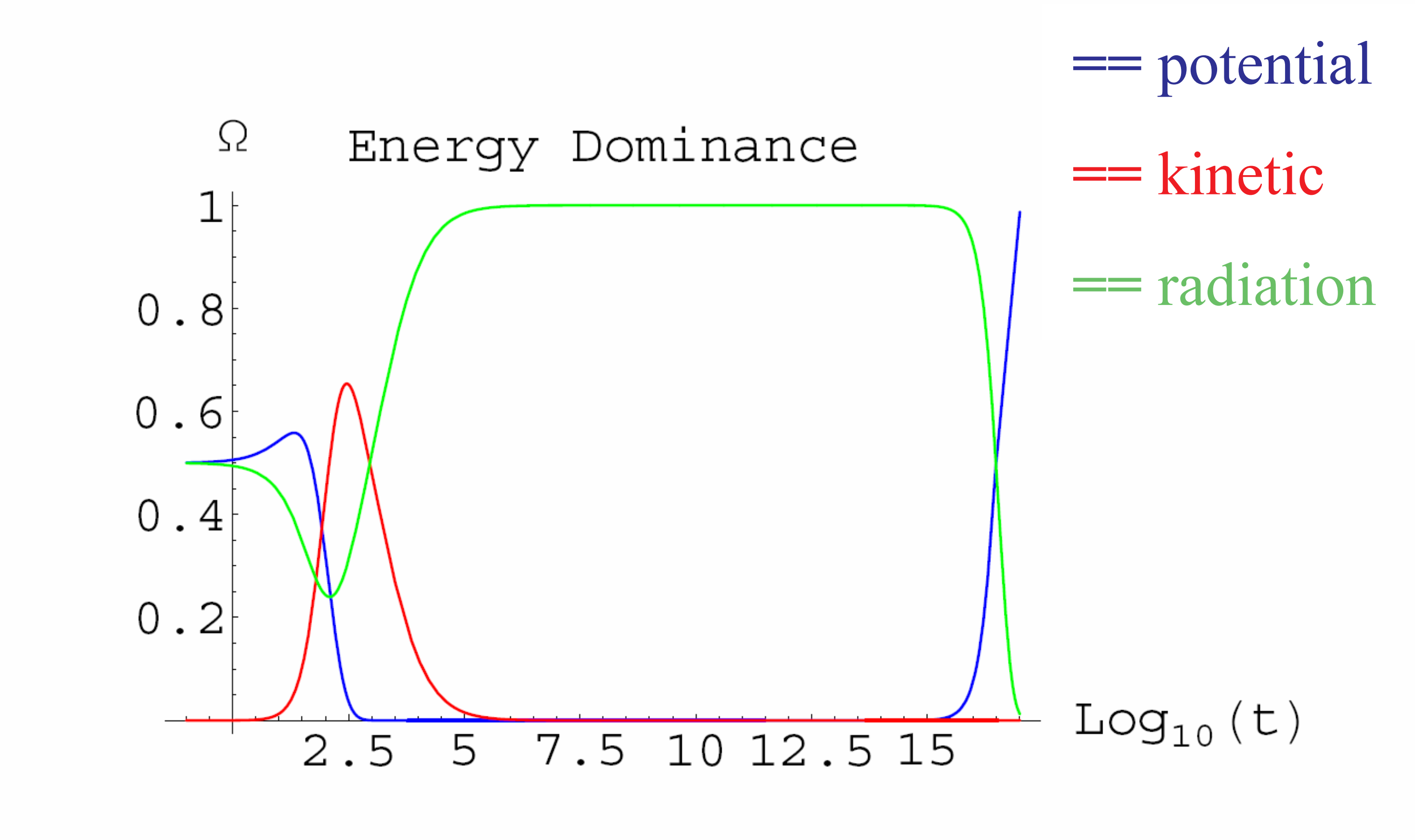
- The 3 phases of evolution $\ddot{\phi} + 3H\dot{\phi} + \frac{\partial V}{\partial \phi} = 0$
  - Potential push: jump $\ddot{\phi} + \cancel{3H}\dot{\phi} + \frac{\partial V}{\partial \phi} = 0$
  - Kinetic : glide $\ddot{\phi} + 3H\dot{\phi} + \cancel{\frac{\partial V}{\partial \phi}} = 0$
  - Radiation : parachute opens $\ddot{\phi} + 3H\dot{\phi} + \cancel{\frac{\partial V}{\partial \phi}} = 0$



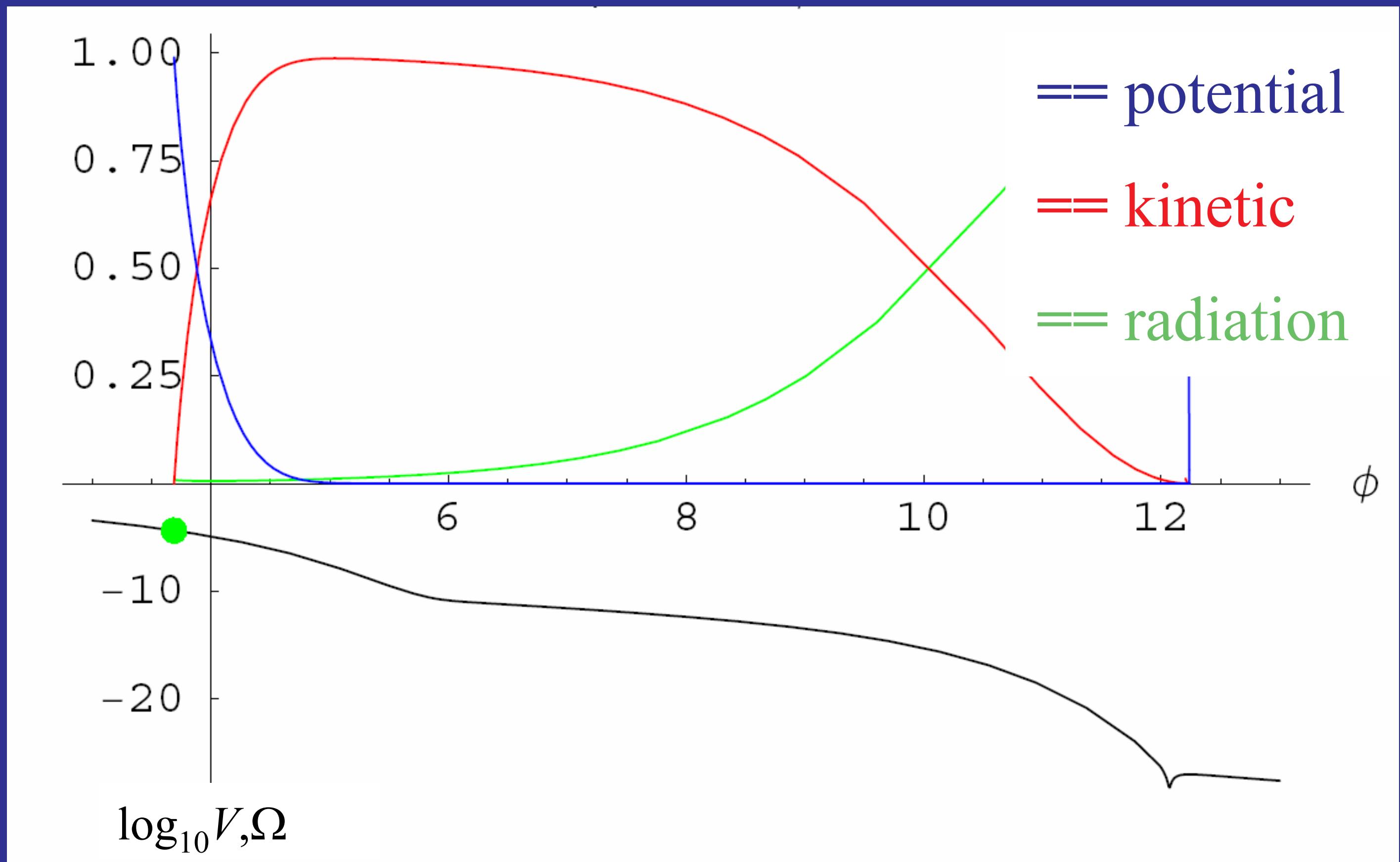
Inflation is only ~ 1/100 worth of tuning away!

Previously:
Barreiro et al: tracking
Huey et al, specific temp. couplings

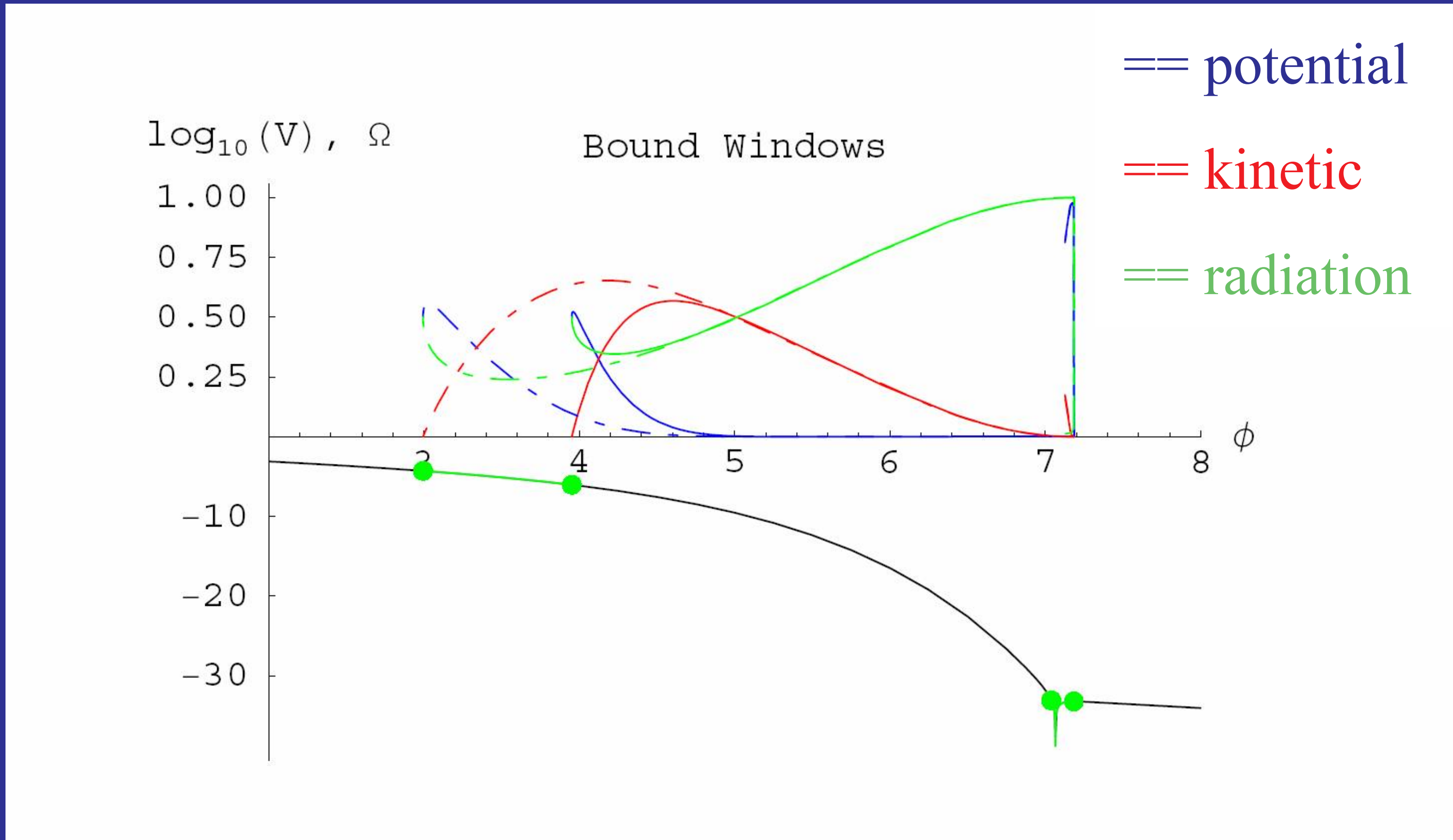
Example: different phases



Example: different phases



Example: trapped field



Summary and Conclusions

- Enough tuning power to resolve outstanding issues
- Need to work out specific models

- Uniqueness and predictability ?