Dark Energy as Guidance

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SYSTEMS OF UNITS

- Three (among seven) base units:
  - Time
  - Length
  - Mass
- Examples:
  - MKS Systems (including the International System)
  - cgs Systems (including the Gaussian System)

SYSTEMS OF UNITS

- Three (among seven) base units:
  - Time
  - Length
  - Mass
- Natural units: $\mathrm{c} = \hbar = 1$ $M?$
  - Planck units: $M_P = \sqrt{\frac{\hbar c}{G}} = 1$
  - Atomic units: $M_A = m_e = 1$
  - Chromodynamic units: $M_{QCD} = m_p = 1$

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  - Vacuum units: $M_V = \rho_V^{1/4} = 1$

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→ ~~No Cosmological Constant Problem!!~~

→ Vacuum Frame

VACUUM UNITS

- The vacuum units demands the introduction of the the vacuum frame.

$$c = \hbar = \rho_V^{1/4} = 1$$

Vacuum standard

VACUUM UNITS

- The vacuum units demands the introduction of the the vacuum frame.

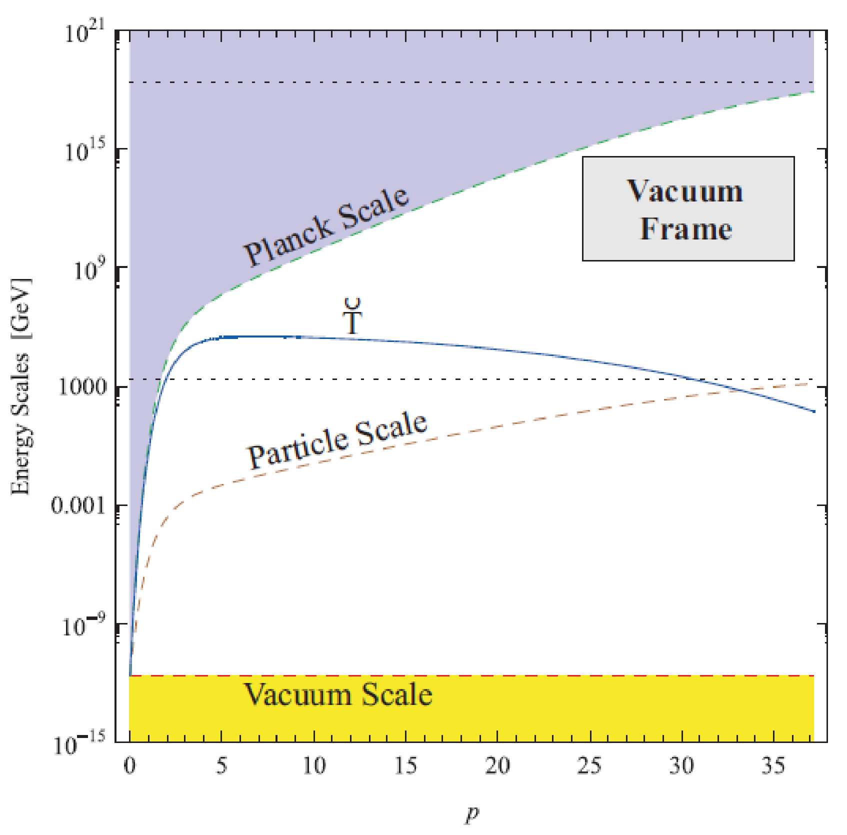
$$c = \hbar = \rho_V^{1/4} = 1$$

- Conditions:
  - Dark energy needs to be different from zero
  - It cannot be conformal invariant.

Vacuum Frame

$$S = \int d^4x\sqrt{-\breve{g}}\left[\frac{\breve{\varphi}^2}{2}\breve{R} - \frac{\breve{\omega}(\breve{\varphi})}{2}\,\breve{g}^{\mu\nu}\breve{\varphi}_{,\mu}\breve{\varphi}_{,\nu} - \breve{\Lambda}^4\right] + \breve{S}_{\rm SM}[\breve{g}_{\mu\nu};\breve{\psi};\breve{\varphi}]\,,$$

$$S_{SM}[\breve{g}_{\mu\nu};\breve{\psi};\breve{\varphi}] = S_{\rm Conf}[\breve{g}_{\mu\nu};\breve{\psi}] + \int d^4x\sqrt{-\breve{g}}\,\frac{\varsigma^2}{2}\breve{\Lambda}\,\breve{\varphi}\,\breve{\Phi}^\dagger\breve{\Phi}\,,$$



- Parameters:

$$\breve{\omega}(\breve{\varphi}) = \frac{1}{2}\left(\alpha^{-2}(\breve{\varphi}/\breve{\Lambda}) - 12\right)\,. \qquad \breve{\Lambda} \simeq 2.3\times 10^{-12}\ \text{GeV}$$

$$\alpha^2(x) = \beta\,(b - \ln x)\,.$$

- Numerical values:

$$\breve{\varphi}_{\rm ini} = \breve{\Lambda}, \rightarrow \breve{M}_{\rm Pl}(\varphi_{\rm ini}) = \breve{\Lambda}.$$

$$b = \ln[M^*_{\rm Pl}/\breve{\Lambda}] \sim 69. \qquad \varsigma \simeq 0.038 \qquad \beta = 80.$$

Jordan Frame

$$S = \int d^4x\sqrt{-g}\left[\frac{\mu\,\varphi}{2}\,R - \frac{\mu\,\omega(\varphi)}{2\,\varphi}\,g^{\mu\nu}\varphi_{,\mu}\varphi_{,\nu} - \frac{\mu^6}{\varphi^2}\right] + S_{\rm SM}[g_{\mu\nu};\psi]\,.$$

$$g_{\mu\nu} = (\breve{\varphi}/M^*_{\rm Pl})\,\breve{g}_{\mu\nu}\,, \qquad \breve{\varphi}/\breve{\Lambda} \equiv \varphi/\mu\,,$$

$$S_{SM}[g_{\mu\nu};\psi] = S_{\rm Conf}[g_{\mu\nu};\psi] + \int d^4x\sqrt{-g}\,\frac{(\varsigma\,\mu)^2}{2}\,\Phi^\dagger\Phi\,.$$

- Parameters:

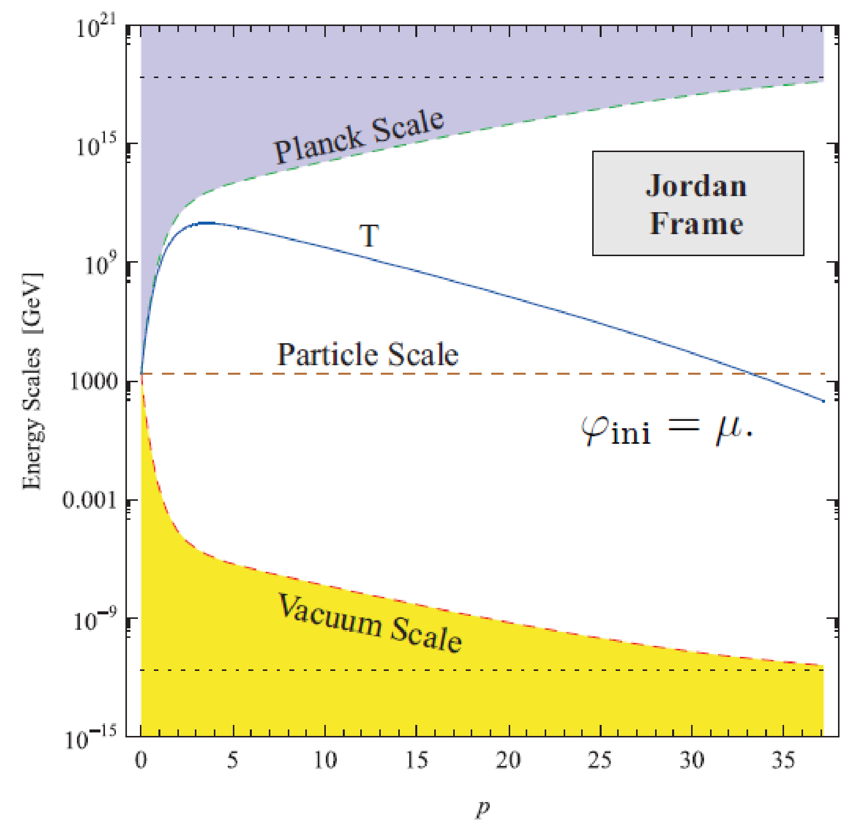
$$\omega(\varphi) = \frac{1}{2}\left(\alpha^{-2}(\varphi/\mu) - 3\right)\,, \qquad \mu \equiv \sqrt{\breve{\Lambda}\,M^*_{\rm Pl}} \simeq 2.4\ {\rm TeV}$$

$$\alpha^2(x) = \beta\,(b - \ln x)\,.$$

- Numerical values:

$\varphi_{\rm ini} = \mu.$ → $M_{\rm Pl}(\varphi_{\rm ini}) = \mu.$

$b = \ln[M^*_{\rm Pl}/\breve{\Lambda}] \sim 69.$ $\quad \varsigma \simeq 0.038$, $\beta = 80.$



Einstein Frame

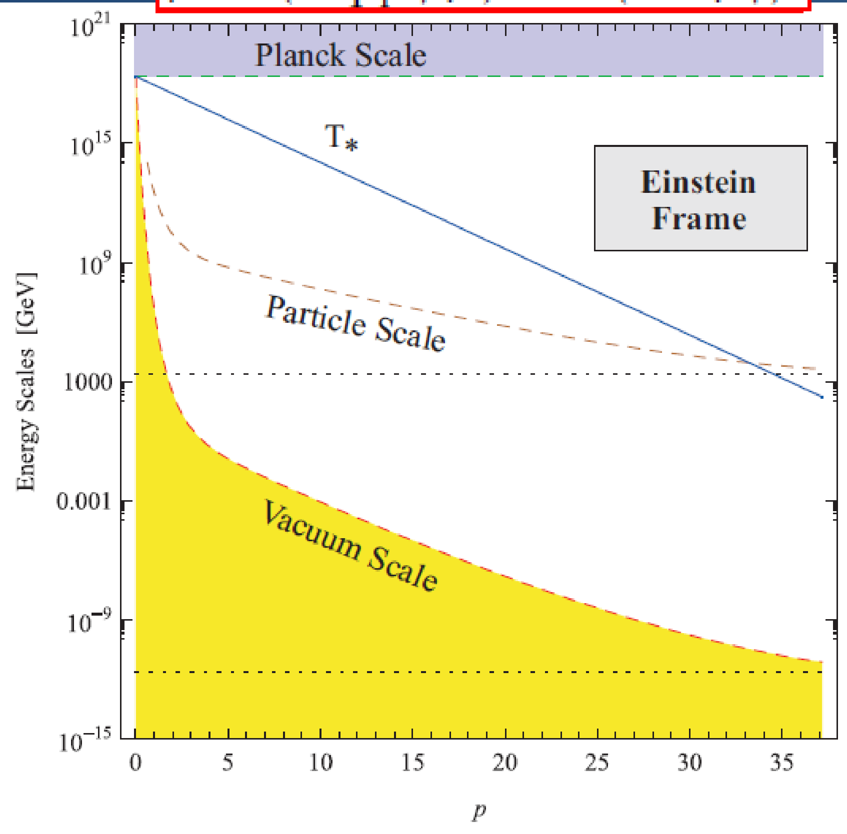
$$S = \int \frac{d^4x}{16\pi G_*}\sqrt{-g_*}\,[R_* - 2g_*^{\mu\nu}\partial_\mu\varphi_*\partial_\nu\varphi_* - 4V_*(\varphi_*)] + S_m[A^2(\varphi_*)g^*_{\mu\nu};\psi]\,.$$

$$g_{\mu\nu} = A^2(\varphi)g^*_{\mu\nu}\,,$$

$$A^2 = {M^*_{\rm Pl}}^2/(\mu\,\varphi) = \exp(\beta\varphi_*^2),$$

$$\varphi = ({M^*_{\rm Pl}}^2/\mu)\,\exp(-\beta\varphi_*^2).$$

$$S_{SM}[A^2(\varphi_*)\,g^*_{\mu\nu};\psi_*] = S_{\rm Conf}[g^*_{\mu\nu};\psi^*] + \int d^4x\sqrt{-g_*}\,\frac{(\varsigma\,M^*_{\rm Pl})^2}{2}\,{\Phi_*}^\dagger\Phi_*\,e^{\beta[\varphi_*^2-\varphi^2_{*\,\rm ini}]}\,.$$



- Potential:

$$2\,V_*(\varphi_*) \equiv \frac{\hat V_*(\varphi_*)}{{M^*_{\rm Pl}}^2} = {M^*_{\rm Pl}}^2\,e^{4\,\beta[\varphi_*^2-\varphi^2_{*\,\rm ini}]}\,.$$

- Numerical values:

$$M^*_{\rm Pl} \equiv (8\pi G_*)^{-1/2} \simeq 2.4\times 10^{18}\ {\rm GeV}$$

$$\varphi^2_{*\,\rm ini} \equiv b/\beta \sim 1.$$

$$\varsigma \simeq 0.038$$

$$\beta = 80.$$

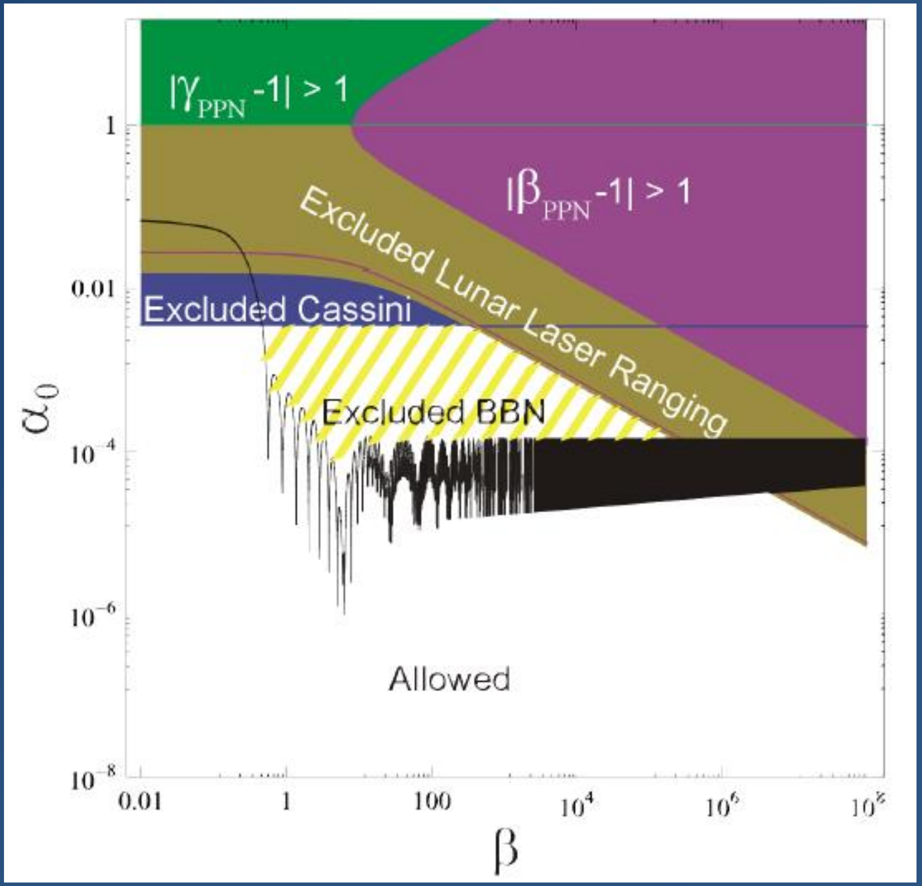
Constraints and Signatures

Post-Newtonian Parameters:

- **Time delay of the Cassini Spacecraft.**
- **Lunar Laser Ranging Experiment.**
- **Perturbative limits**

BBN constraints:

- **^{4}He**



$$\alpha_0 \equiv \beta\varphi_*^0$$

Summary

- We have discussed the meaning of a cosmological constant in comparison with a general dark energy model.
- This discussion suggests the introduction of what we call 'Vacuum Frame'.
- Single-Scale Model constitutes a simple example of a GR attractor provided by:
  - Modifications to ideal radiation thermal bath
  - Mass thresholds
  - Vacuum energy itself