Title: An Unparticle Solution to the Hierarchy Problem

Date: May 07, 2010 02:30 PM

URL: http://pirsa.org/10050014

Abstract: The Planck-weak hierarchy is investigated in an extradimensional, soft-wall model originally proposed by Batell and Gherghetta. In this model the soft-wall is dynamically generated by background $\ddot{\eta}$ -elds that, in the Einstein frame, cause the metric factor to deviate from anti-de Sitter by a power-law of the conformal coordinate. This talk will demonstrate that in order to achieve the appropriate Planck-weak hierarchy, the power of the conformal coordinate must be less than one. This in turn implies that the gravitational sector contains scalar $\ddot{\eta}$ -elds that act like unparticles without a mass gap.

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Unparticle Solution to Hierarchy

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University of Melbourne

May 7, 2010

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Introduction

The BG Soft-Wall Model

Achieving the Hierarchy

Fluctuations

Bulk Fields

Summary

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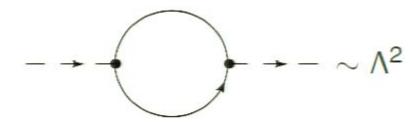
Introduction

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Introduction

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Higgs boson sensitive to highest scale of new physics



- With only Standard Model, new physics is Planck scale
- Need a way to separate $M_{\rm Pl}\sim 10^{19}$ GeV and $v_{wk}\sim 1$ TeV
- Warped Extra Dimension provides a way

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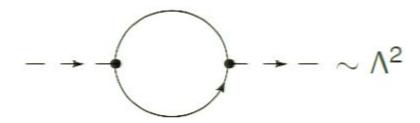
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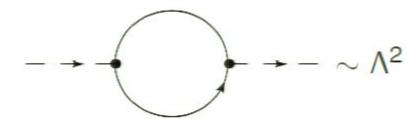
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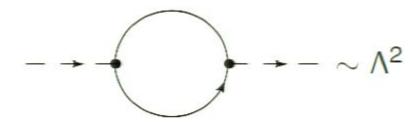
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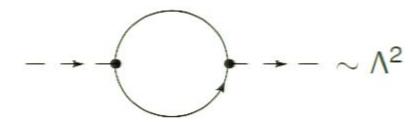
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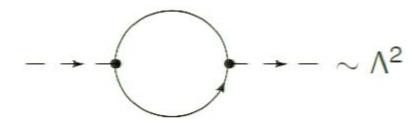
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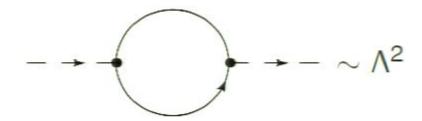
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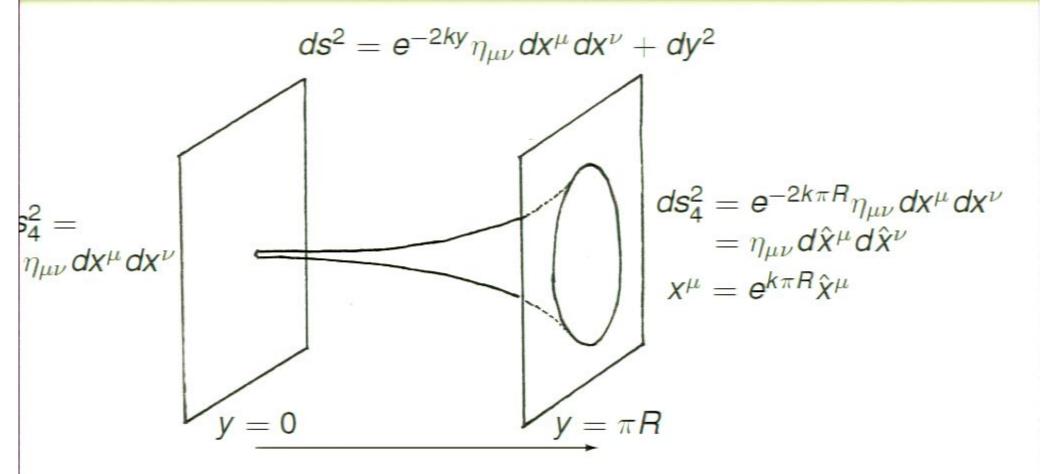


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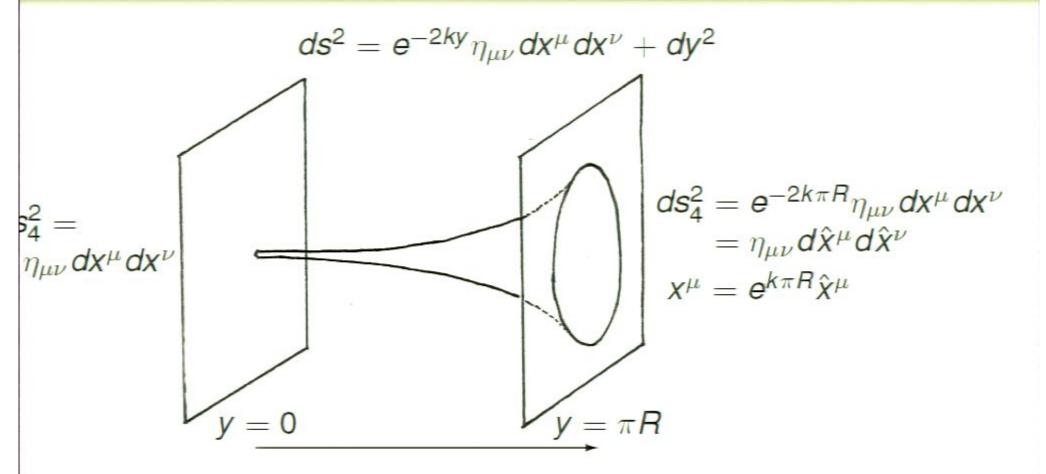
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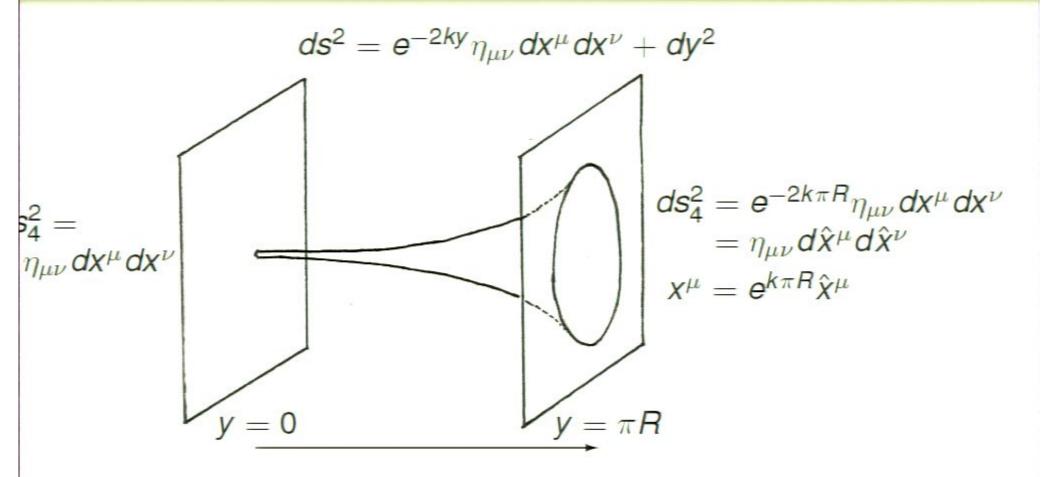
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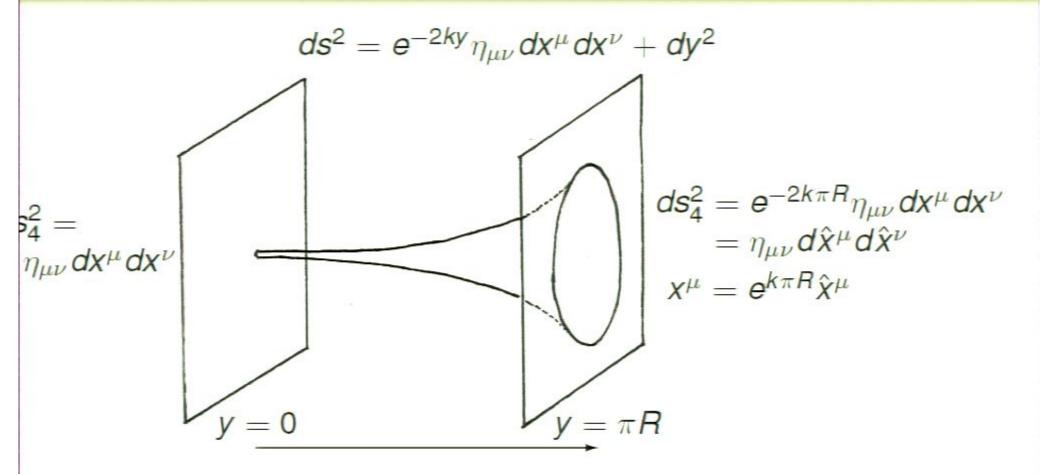
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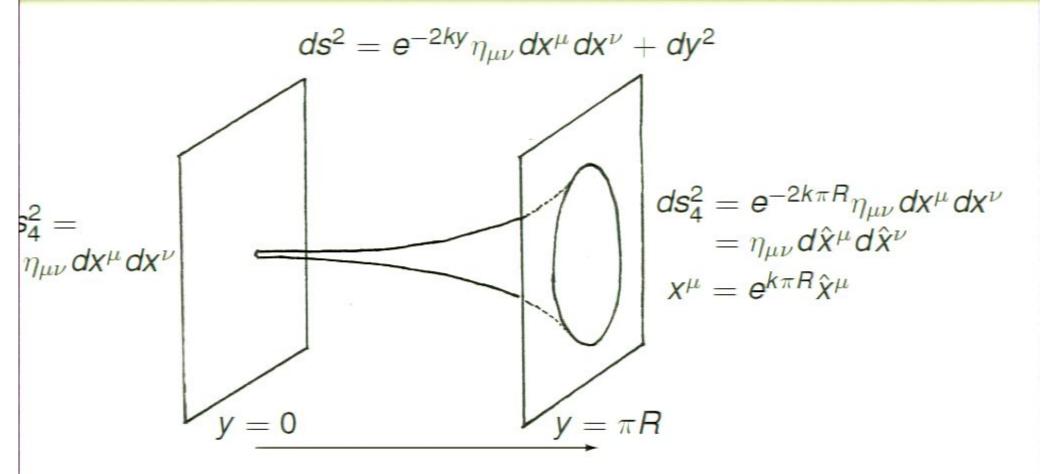
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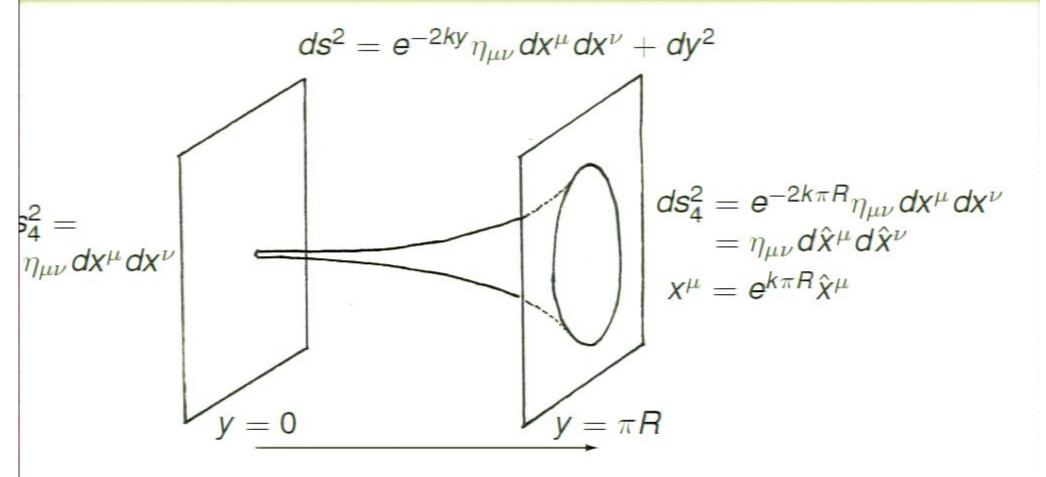
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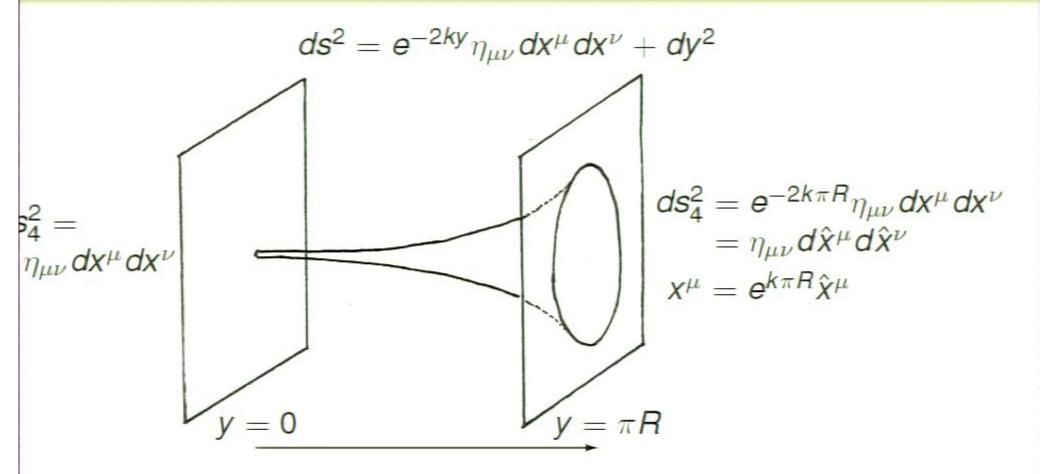
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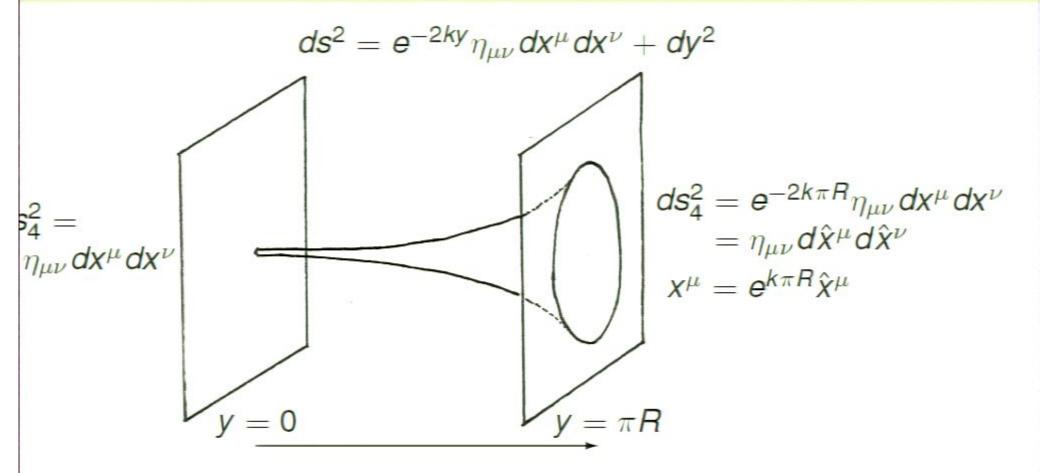
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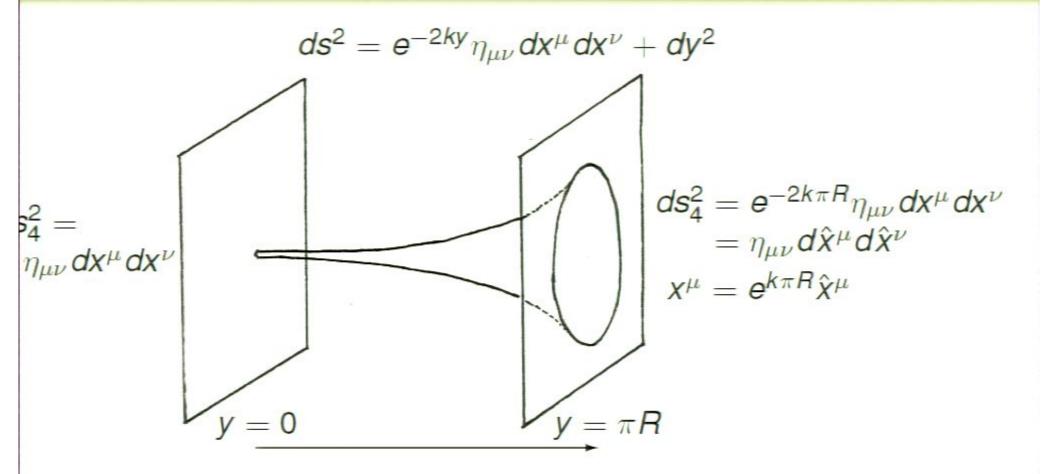
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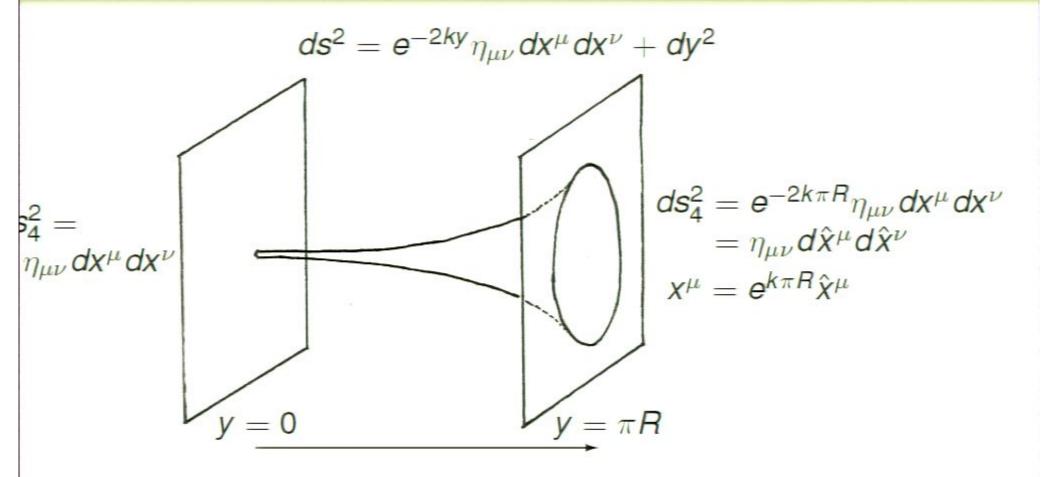
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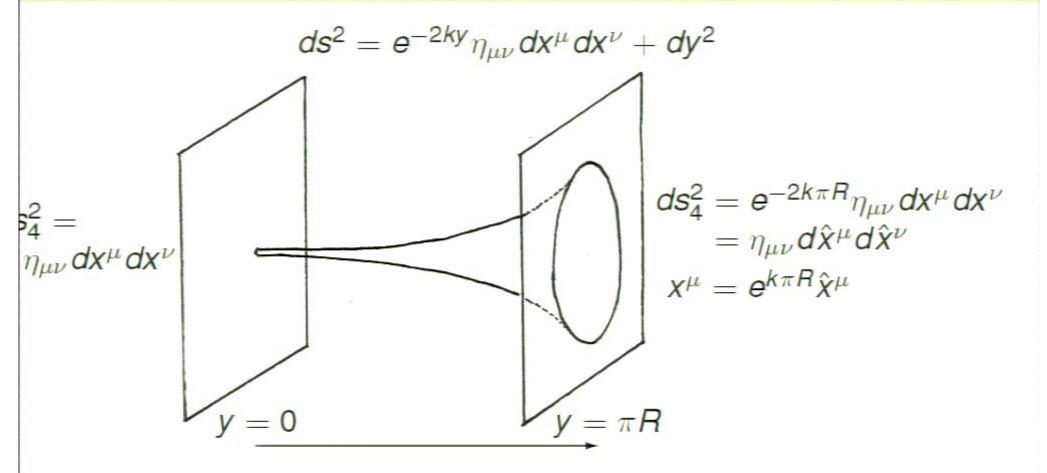
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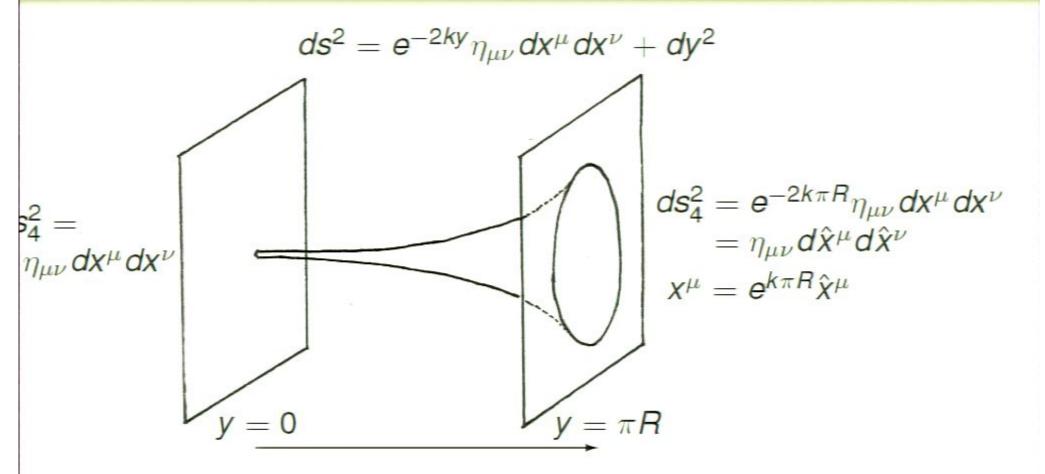
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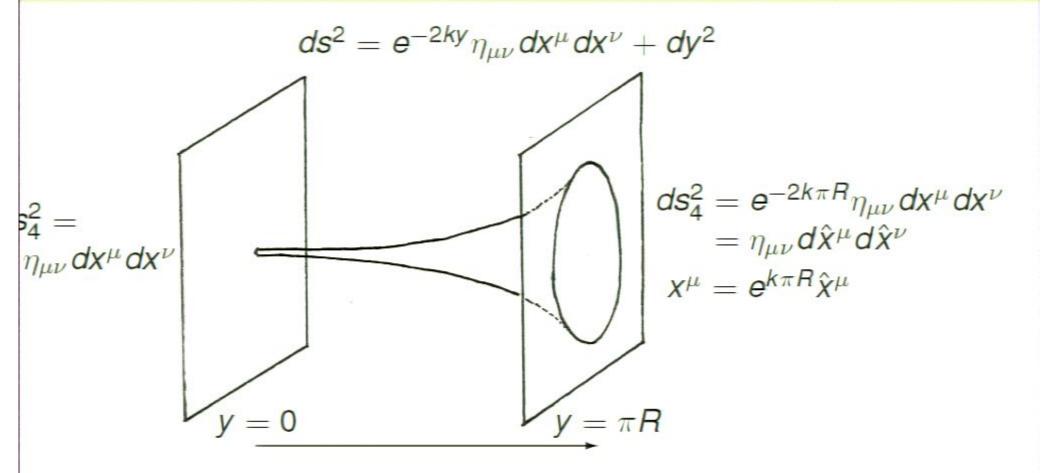
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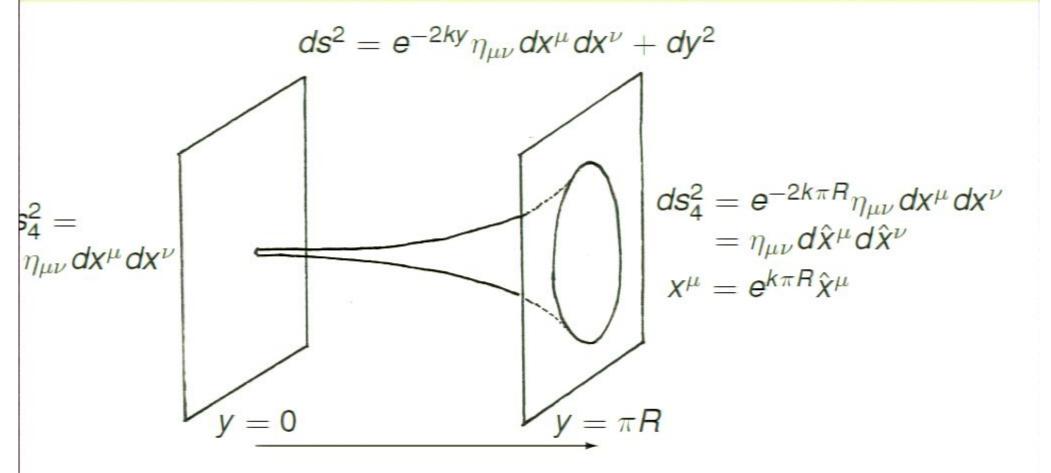
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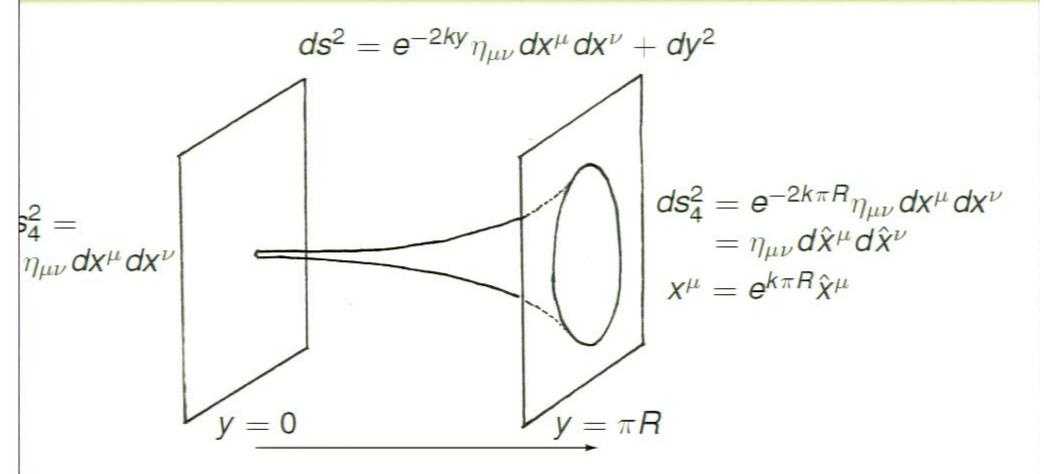
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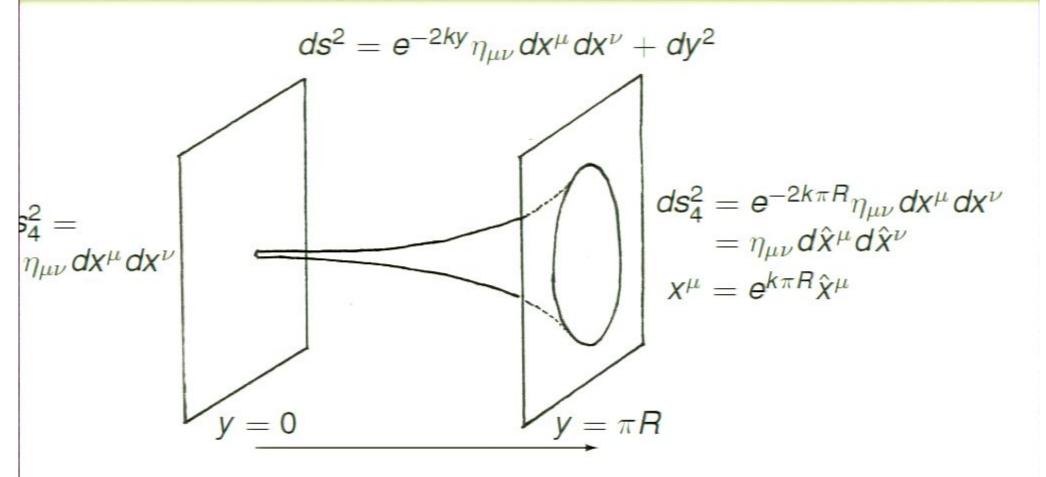
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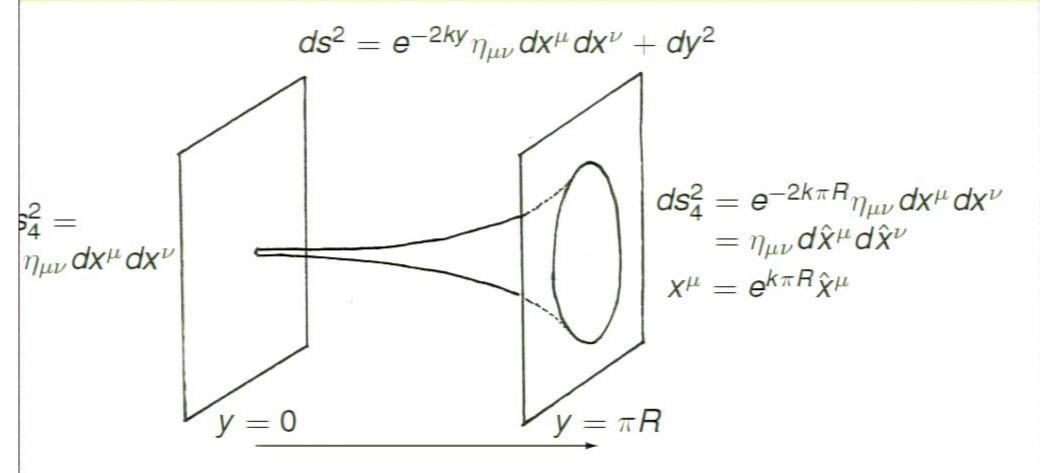
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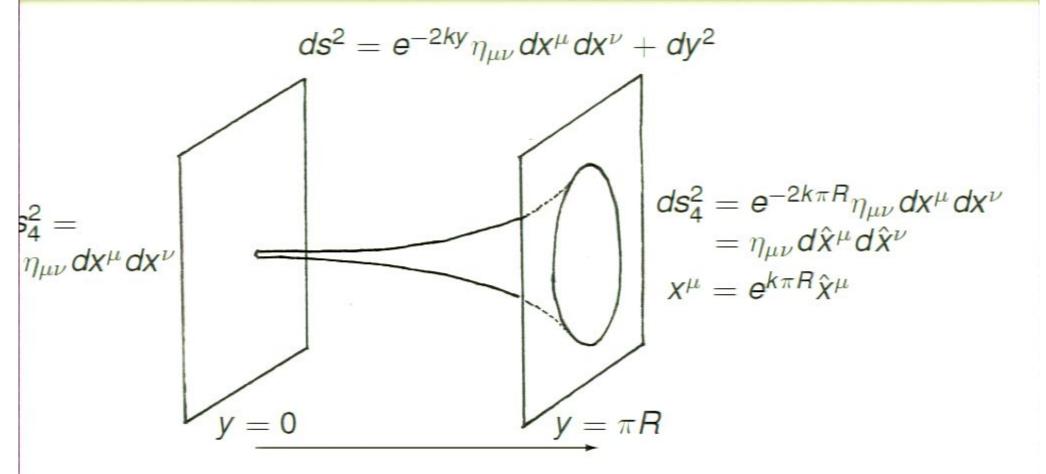
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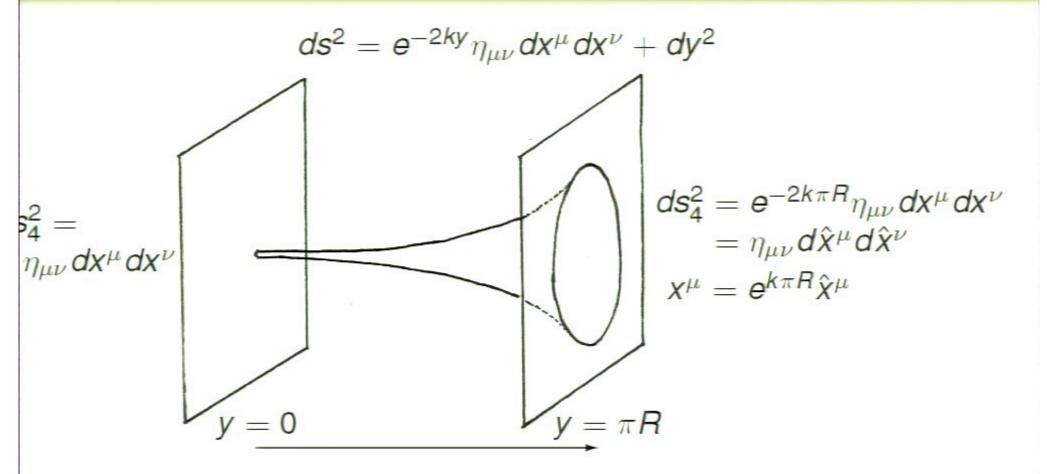
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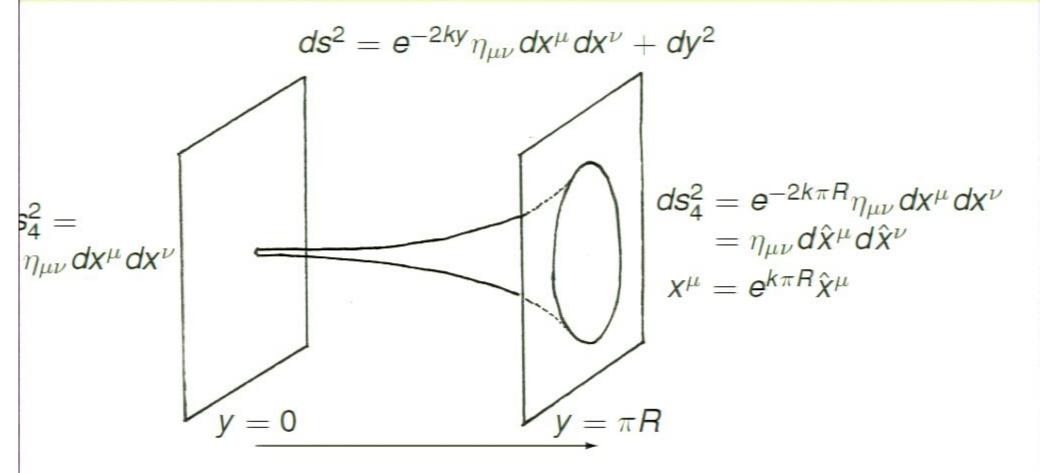
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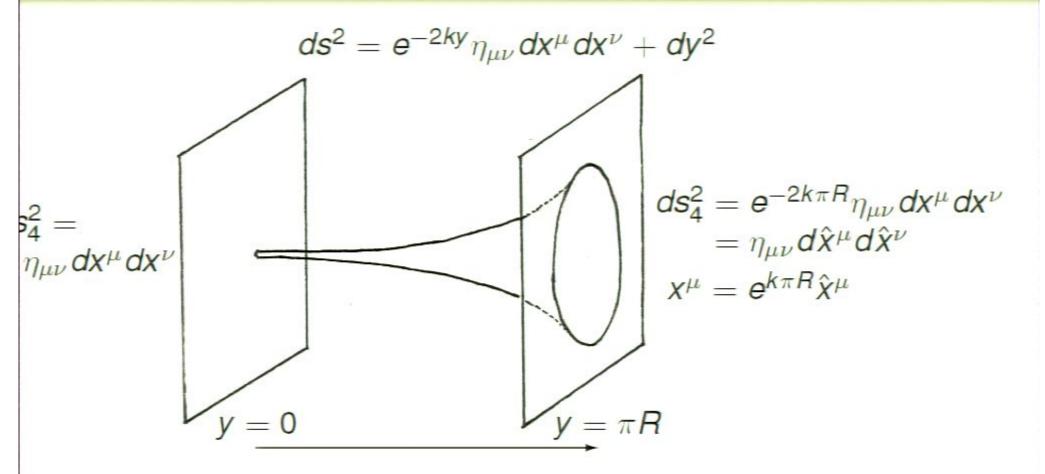
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- Get infinite extra dimension
- Single massless tensor mode (graviton)
- Continuum of tensor modes with $m^2 > 0$
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 - An operator that is non-trivially scale invariant
 - Scale invariance fixes propagator
 - Resulting interpretation of unparticle as a fractional number of massless particles

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Unparticles couple to Standard Model

Higgs VEV breaks conformal invariance at low so
Undarticle conformal invariance broken [Fox. Reja

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So how to define unparticle?

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An operator that is conformally invariant
Restricts scaling dimension: 1 of 2

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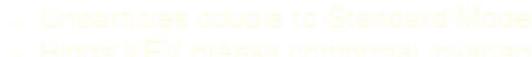


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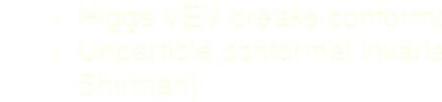
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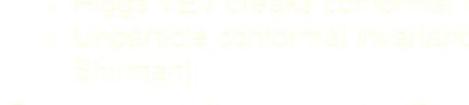
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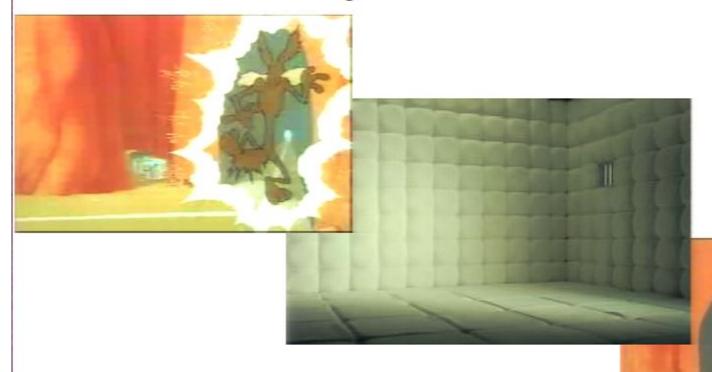




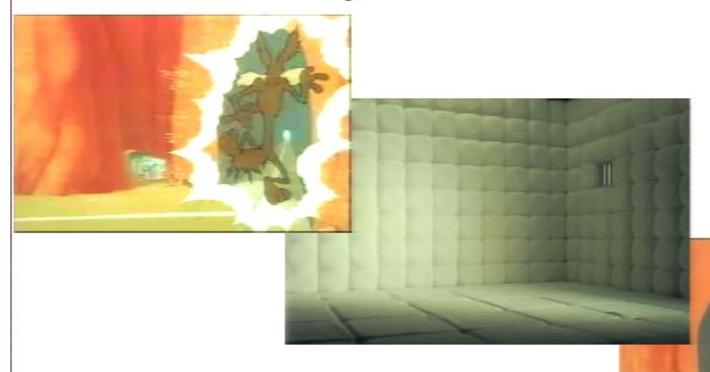




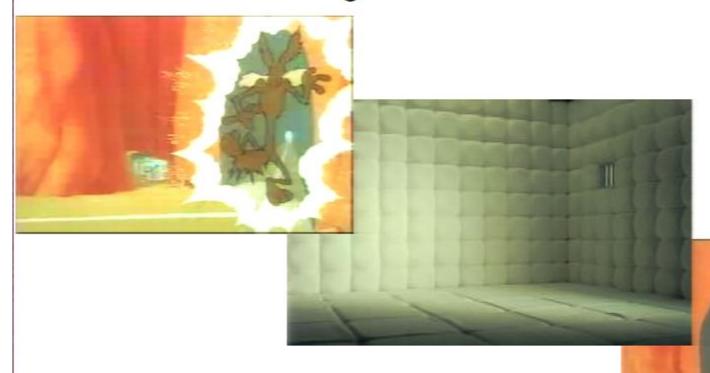
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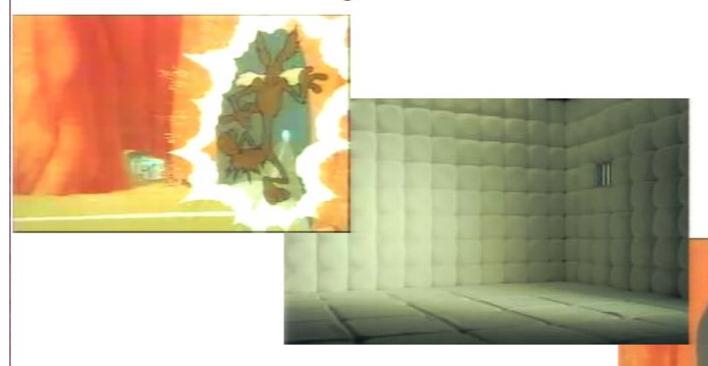
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The BG Soft-Wall Model

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G Soft-Wall Model

tell-Gherghetta Soft-Wall

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- A Real Scalar (the "Dilaton") with power-law VEV
- Conformally equivalent to pure AdS in "string" frame
- Requires at least two real scalars (φ, T)

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metric factor:
$$A(z) = \ln kz + \frac{2}{3}(\mu z)^{\nu}$$

dilaton:
$$\langle \phi \rangle = \sqrt{\frac{8}{3}} (\mu z)^{\nu}$$

tachyon:
$$\langle T \rangle = 4\sqrt{\frac{1+\nu}{\nu}}(\mu z)^{\nu/2}$$

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- A Real Scalar (the "Dilaton") with power-law VEV
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- Requires at least two real scalars (φ, T)

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metric factor:
$$A(z) = \ln kz + \frac{2}{3}(\mu z)^{\nu}$$

dilaton:
$$\langle \phi \rangle = \sqrt{\frac{8}{3}(\mu z)^{\nu}}$$

tachyon:
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Pirsa: 10050014

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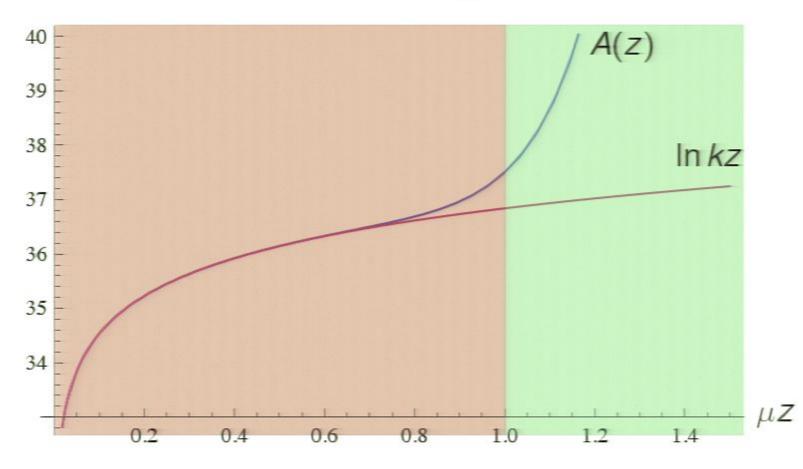
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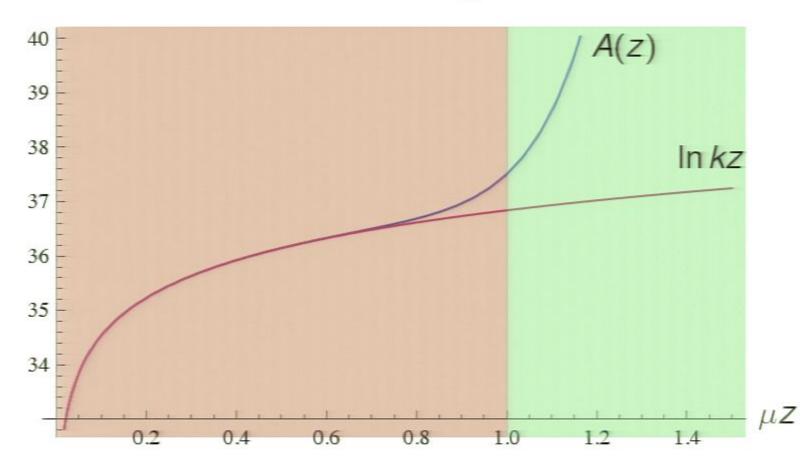
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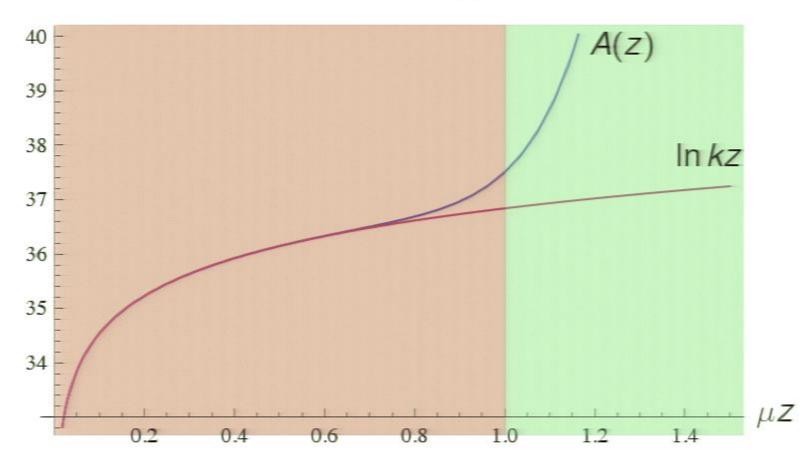
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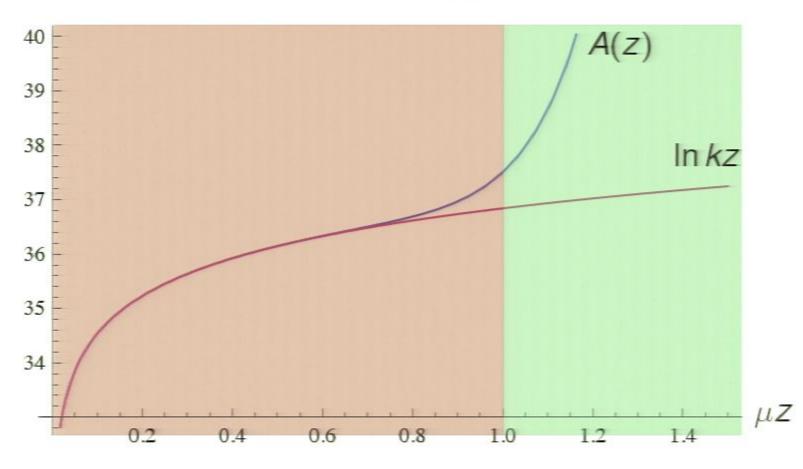
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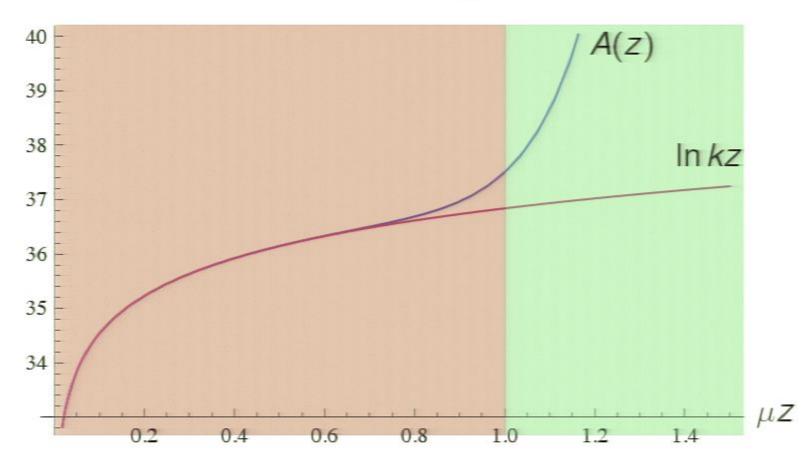
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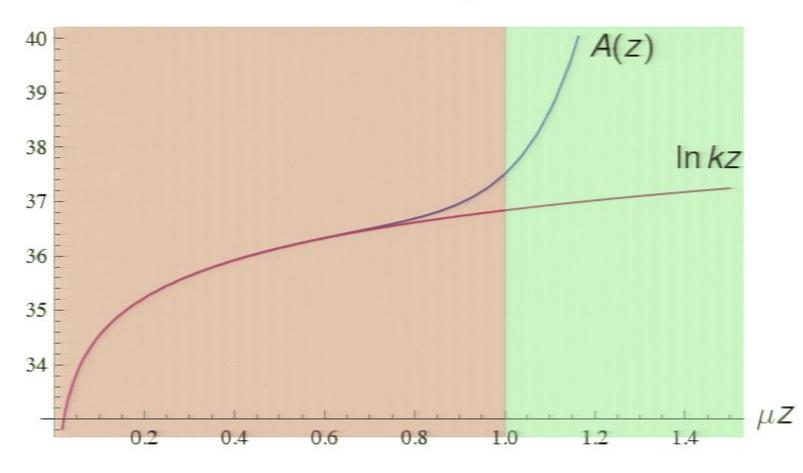
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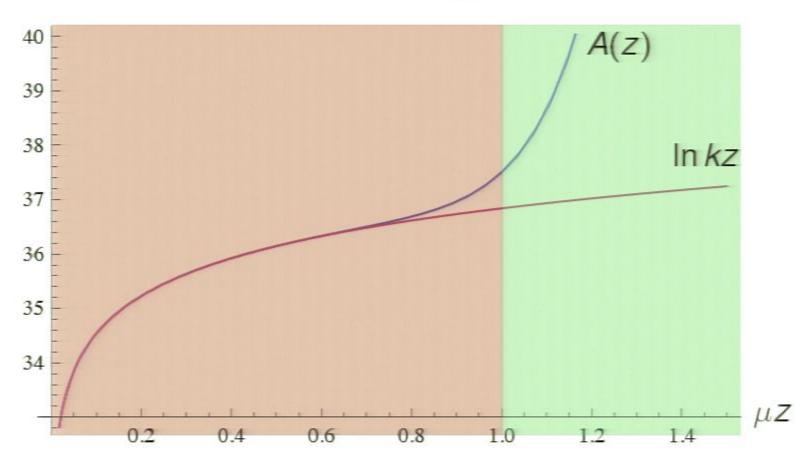
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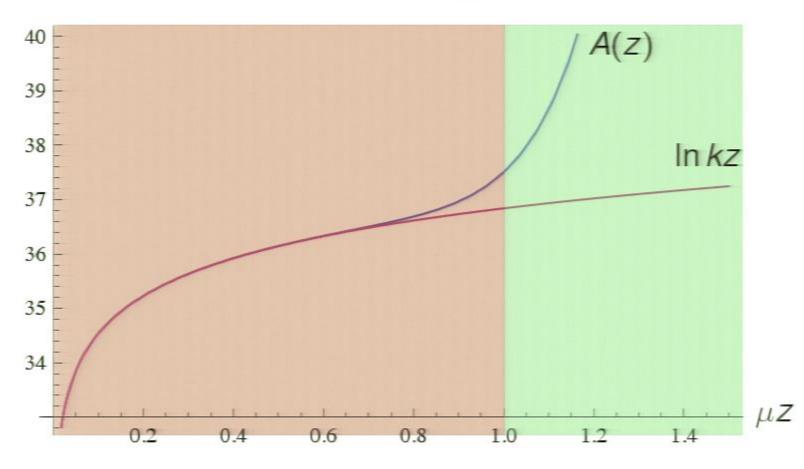
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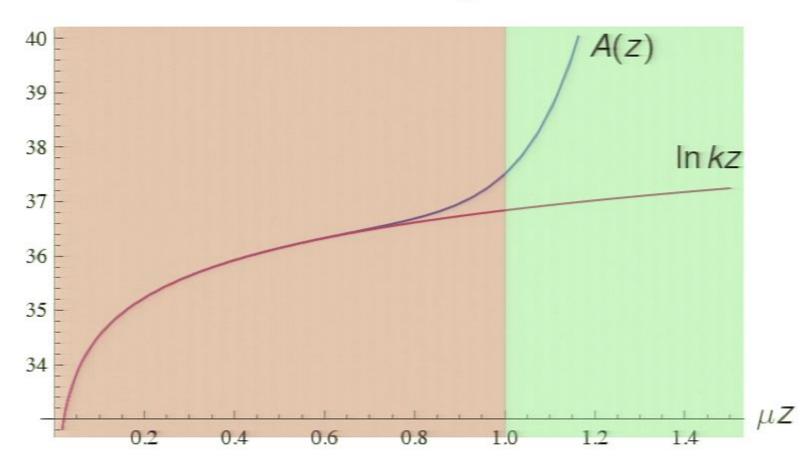
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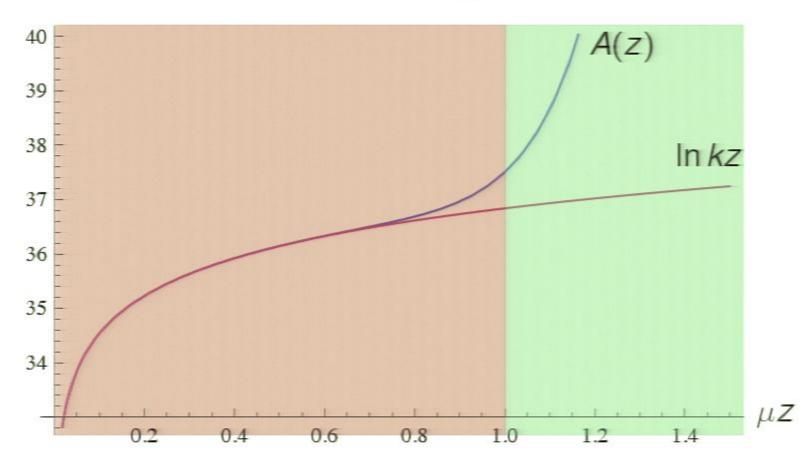
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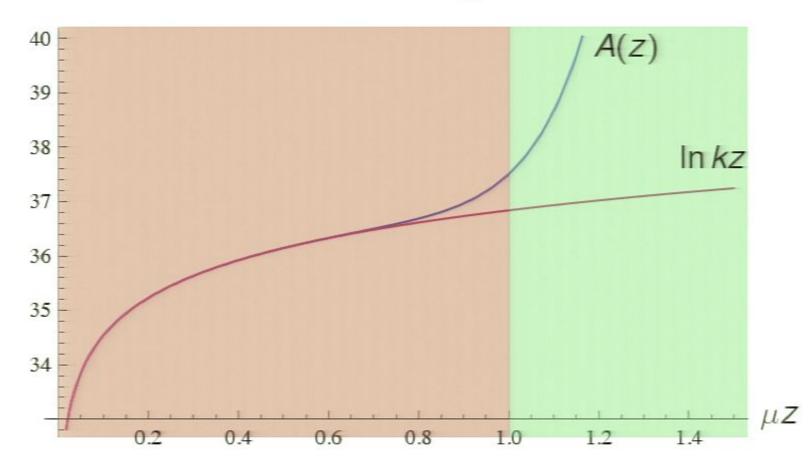
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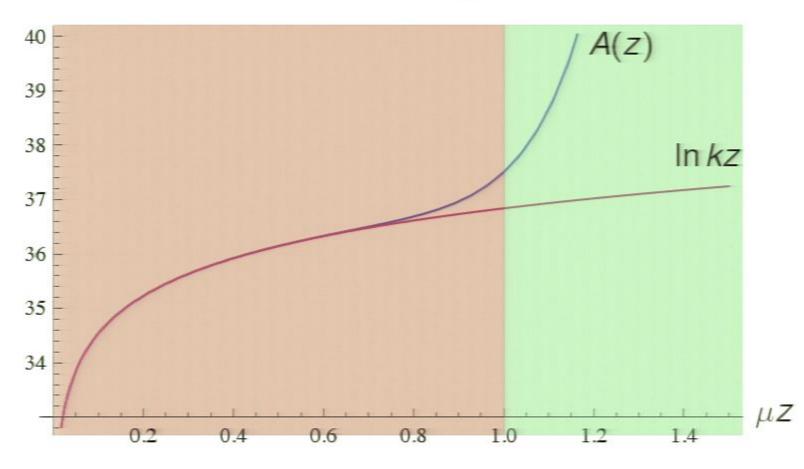
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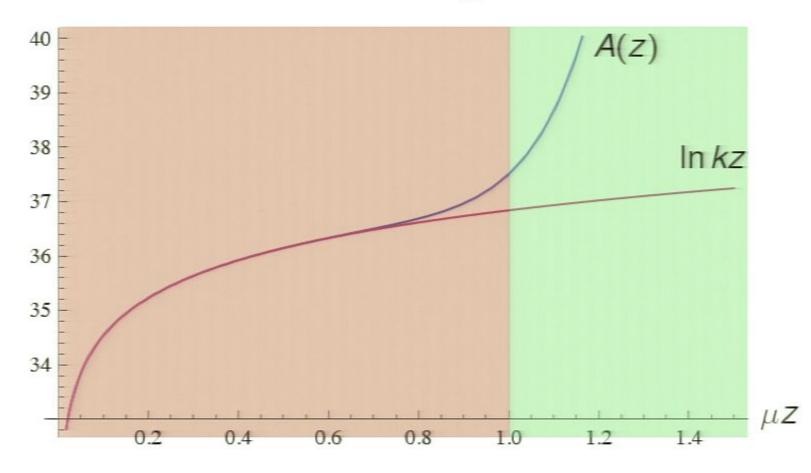
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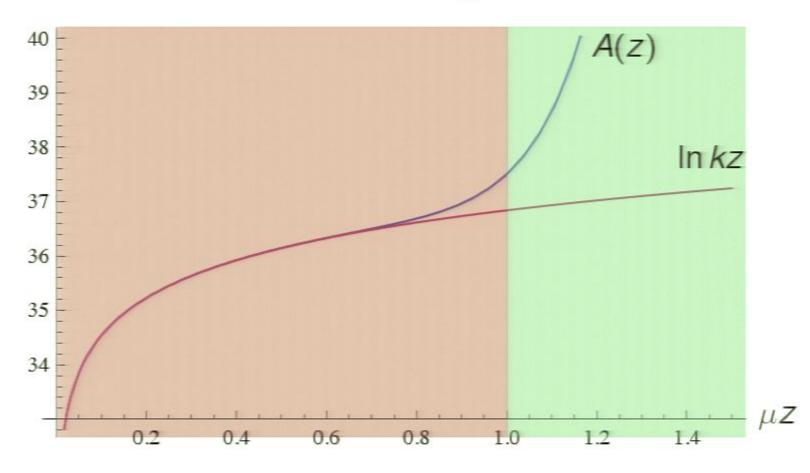
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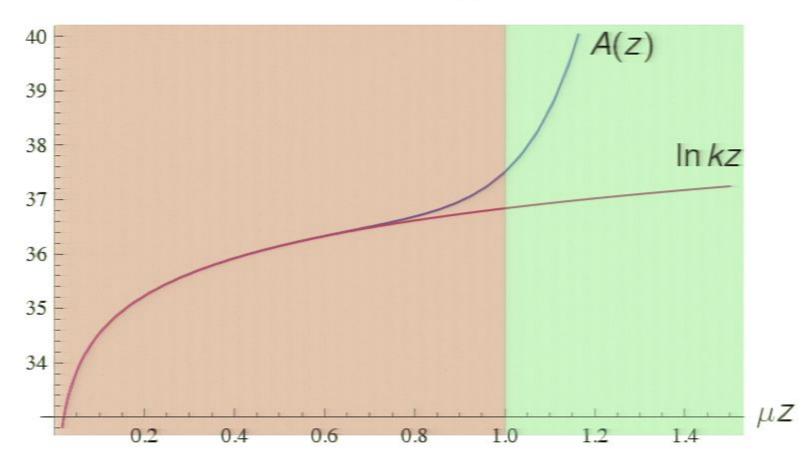
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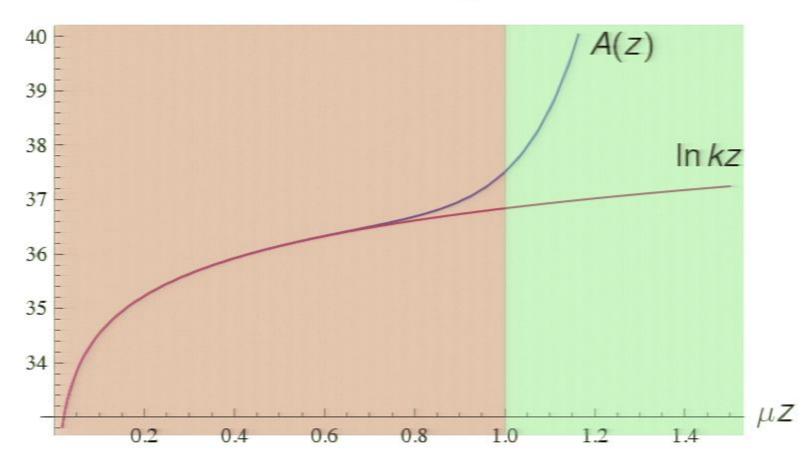
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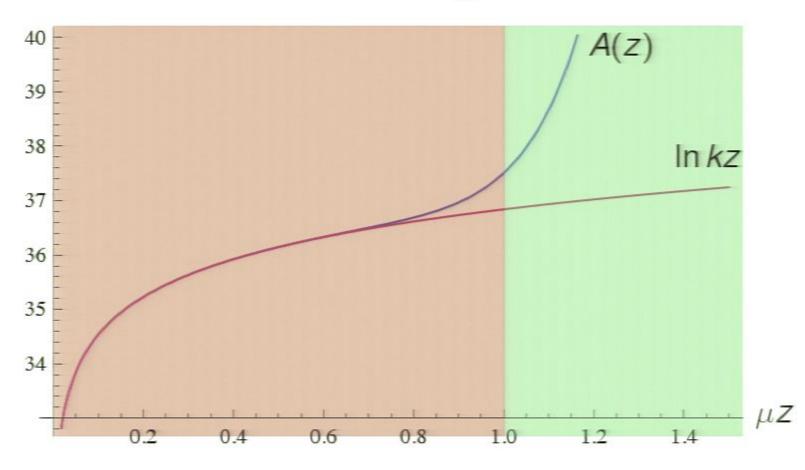
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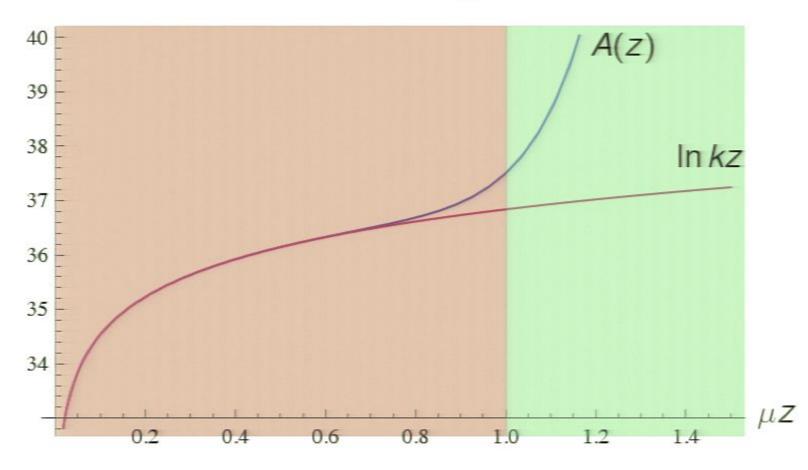
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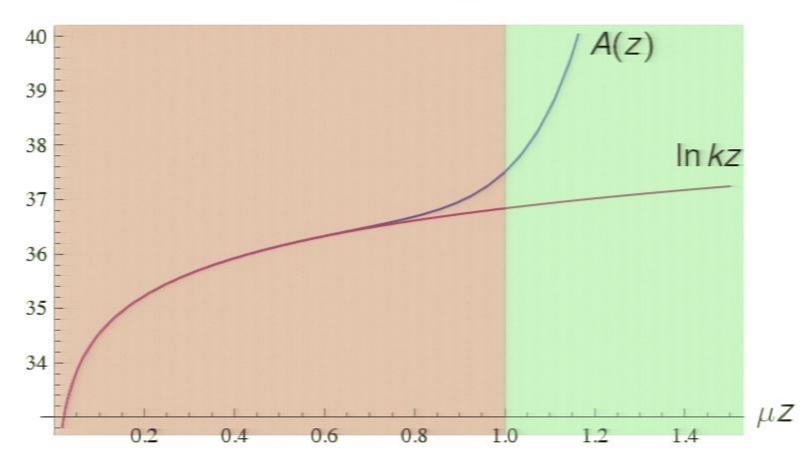
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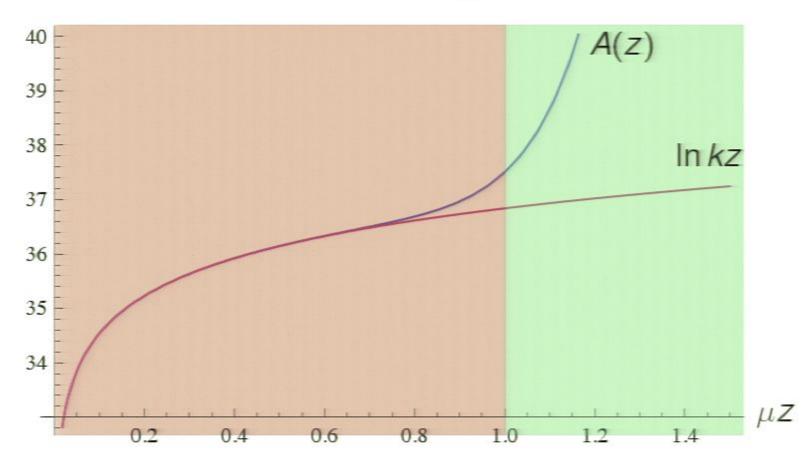
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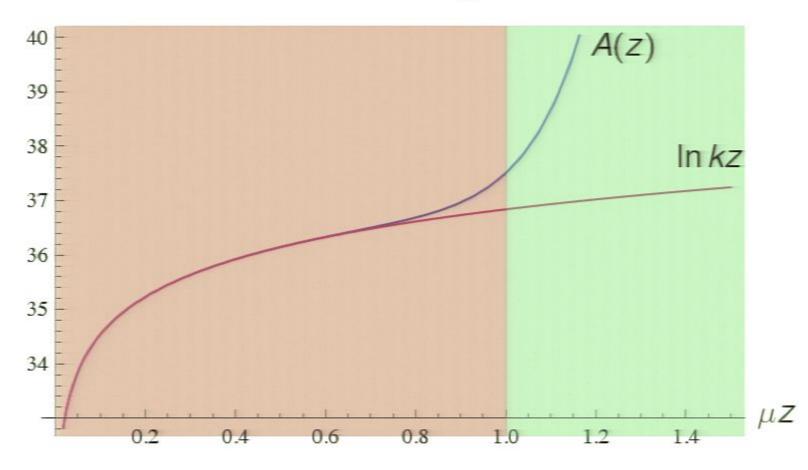
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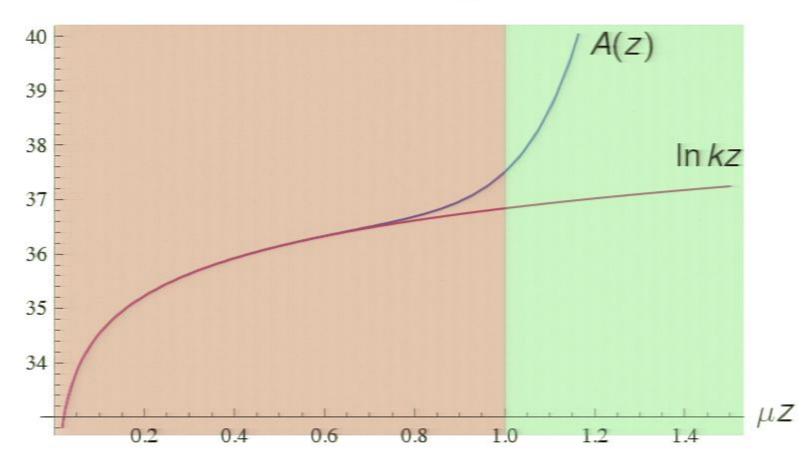
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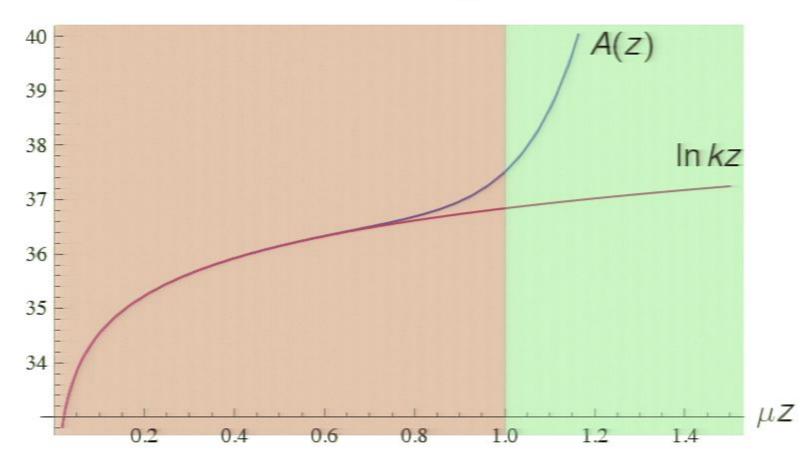
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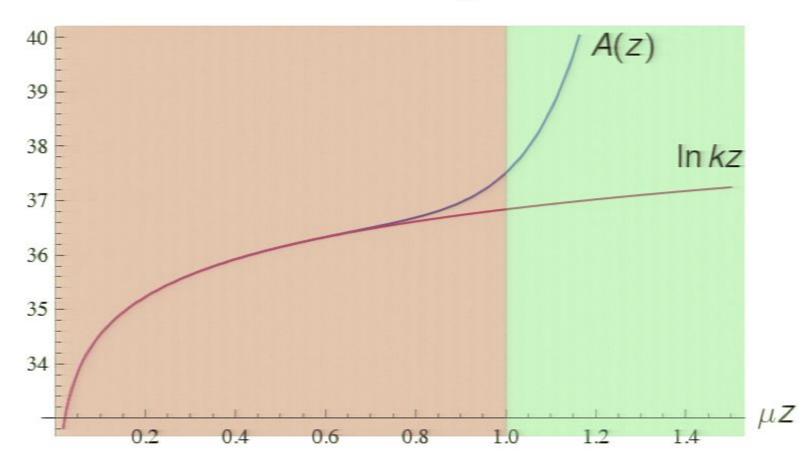
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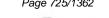
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 - Relates bulk potential to function W
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 - Converts Einstein equations to first-order

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Pirsa: 10050014 Page 814/136

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Pirsa: 10050014 Page 816/1362

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 - Relates bulk potential to function W
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 - Converts Einstein equations to first-order

$$e^{A(z)}\partial_z A(z) = 2W$$

 $e^{A(z)}\partial_z \langle \eta \rangle = 6\frac{\partial W}{\partial \eta}$

Pirsa: 10050014 Page 821/1362

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Pirsa: 10050014 Page 822/136

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Pirsa: 10050014 Page 823/136

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Pirsa: 10050014 Page 824/136

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Pirsa: 10050014 Page 826/1362

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Pirsa: 10050014 Page 827/136

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Pirsa: 10050014 Page 828/136

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Pirsa: 10050014 Page 831/136

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Pirsa: 10050014 Page 833/1362

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Pirsa: 10050014 Page 834/1362

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Pirsa: 10050014 Page 835/136

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Pirsa: 10050014 Page 836/136:

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Pirsa: 10050014 Page 837/136

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Pirsa: 10050014 Page 838/1362

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Pirsa: 10050014 Page 839/1362

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Pirsa: 10050014 Page 840/136

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Pirsa: 10050014 Page 841/1362

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Pirsa: 10050014 Page 843/1362

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Pirsa: 10050014 Page 845/1362

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Pirsa: 10050014 Page 880/136

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Pirsa: 10050014 Page 881/136

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Pirsa: 10050014 Page 882/136

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Pirsa: 10050014 Page 883/136

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Pirsa: 10050014 Page 884/136

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$$R(z) = -\frac{4}{3}k^2e^{\frac{4}{3}(\mu z)^{\nu}}\left(4\nu^2(\mu z)^{2\nu} + 4\nu(4-\nu)(\mu z)^{\nu} + 15\right)$$

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$$R(z) = -\frac{4}{3}k^2e^{\frac{4}{3}(\mu z)^{\nu}}\left(4\nu^2(\mu z)^{2\nu} + 4\nu(4-\nu)(\mu z)^{\nu} + 15\right)$$

$$R \to \infty$$
 as $z \to \infty$

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$$R \to \infty$$
 as $z \to \infty$

ngularity at infinity.

vitch to y

$$y(z) = \frac{1}{k\nu} \left[\Gamma(0, \frac{2}{3}(\mu z_0)^{\nu}) - \Gamma(0, \frac{2}{3}(\mu z)^{\nu}) \right]$$

w line element

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^
u + dy^2$$

$$\lim_{z\to\infty}y(z)\equiv y_s=\frac{1}{k\nu}\Gamma(0,\tfrac{2}{3}(\mu z_0)^{\nu})$$

Pirsa: 10050014 Page 898/136

vitch to y

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Pirsa: 10050014 Page 899/136

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Pirsa: 10050014 Page 900/136

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Pirsa: 10050014 Page 901/136

vitch to y

$$y(z) = \frac{1}{k\nu} \left[\Gamma(0, \frac{2}{3}(\mu z_0)^{\nu}) - \Gamma(0, \frac{2}{3}(\mu z)^{\nu}) \right]$$

w line element

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^
u + dy^2$$

$$\lim_{Z\to\infty}y(Z)\equiv y_s=\frac{1}{k\nu}\Gamma(0,\tfrac{2}{3}(\mu Z_0)^{\nu})$$

Pirsa: 10050014 Page 902/136

vitch to y

$$y(z) = \frac{1}{k\nu} \Big[\Gamma(0, \frac{2}{3}(\mu z_0)^{\nu}) - \Gamma(0, \frac{2}{3}(\mu z)^{\nu}) \Big]$$

w line element

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^
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$$\lim_{Z\to\infty}y(z)\equiv y_s=\frac{1}{k\nu}\Gamma(0,\tfrac{2}{3}(\mu z_0)^{\nu})$$

Pirsa: 10050014 Page 903/136

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Pirsa: 10050014 Page 904/136

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Pirsa: 10050014 Page 905/13

vitch to y

$$y(z) = \frac{1}{k\nu} \left[\Gamma(0, \frac{2}{3}(\mu z_0)^{\nu}) - \Gamma(0, \frac{2}{3}(\mu z)^{\nu}) \right]$$

w line element

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^
u + dy^2$$

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Pirsa: 10050014 Page 906/136

vitch to y

$$y(z) = \frac{1}{k\nu} \Big[\Gamma(0, \frac{2}{3}(\mu z_0)^{\nu}) - \Gamma(0, \frac{2}{3}(\mu z)^{\nu}) \Big]$$

w line element

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^
u + dy^2$$

$$\lim_{Z\to\infty}y(Z)\equiv y_s=\frac{1}{k\nu}\Gamma(0,\tfrac{2}{3}(\mu Z_0)^{\nu})$$

Pirsa: 10050014 Page 907/136

vitch to y

$$y(z) = \frac{1}{k\nu} \Big[\Gamma(0, \frac{2}{3}(\mu z_0)^{\nu}) - \Gamma(0, \frac{2}{3}(\mu z)^{\nu}) \Big]$$

w line element

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^
u + dy^2$$

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Pirsa: 10050014 Page 908/136

vitch to y

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Pirsa: 10050014 Page 909/136

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Pirsa: 10050014 Page 910/136

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w line element

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2$$

$$\lim_{z \to \infty} y(z) \equiv y_s = \frac{1}{k\nu} \Gamma(0, \frac{2}{3}(\mu z_0)^{\nu})$$
 Finite

Pirsa: 10050014 Page 911/136

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$$y(z) = \frac{1}{k\nu} \Big[\Gamma(0, \frac{2}{3}(\mu z_0)^{\nu}) - \Gamma(0, \frac{2}{3}(\mu z)^{\nu}) \Big]$$

w line element

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^
u + dy^2$$

$$\lim_{z \to \infty} y(z) \equiv y_s + \frac{1}{k\nu} \Gamma(0, \frac{2}{3}(\mu z_0)^{\nu})$$
 Finite

Pirsa: 10050014 Page 912/1362

vitch to y

$$y(z) = \frac{1}{k\nu} \left[\Gamma(0, \frac{2}{3}(\mu z_0)^{\nu}) - \Gamma(0, \frac{2}{3}(\mu z)^{\nu}) \right]$$

w line element

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^
u + dy^2$$

$$\lim_{z\to\infty}y(z)\equiv y_s = \frac{1}{k\nu}\Gamma(0,\frac{2}{3}(\mu z_0)^{\nu})$$
 Finite

Pirsa: 10050014 Page 913/136

vitch to y

$$y(z) = \frac{1}{k\nu} \left[\Gamma(0, \frac{2}{3}(\mu z_0)^{\nu}) - \Gamma(0, \frac{2}{3}(\mu z)^{\nu}) \right]$$

w line element

$$ds^2 = e^{-2A(y)} \eta_{\mu\nu} dx^{\mu} dx^{\nu} + dy^2$$

$$\lim_{z\to\infty}y(z)\equiv y_s \pm \frac{1}{k\nu}\Gamma\big(0,\tfrac{2}{3}(\mu z_0)^\nu\big)$$
 Finite

Pirsa: 10050014

vitch to y

$$y(z) = \frac{1}{k\nu} \Big[\Gamma(0, \frac{2}{3}(\mu z_0)^{\nu}) - \Gamma(0, \frac{2}{3}(\mu z)^{\nu}) \Big]$$

w line element

$$ds^2 = e^{-2A(y)} \eta_{\mu\nu} dx^{\mu} dx^{\nu} + dy^2$$

$$\lim_{z \to \infty} y(z) \equiv y_s + \frac{1}{k\nu} \Gamma(0, \frac{2}{3} (\mu z_0)^{\nu})$$
 Finite

Pirsa: 10050014

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$$\lim_{z \to \infty} y(z) \equiv y_s + \frac{1}{k\nu} \Gamma(0, \frac{2}{3}(\mu z_0)^{\nu})$$
 Finite

Pirsa: 10050014

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w line element

$$ds^2 = e^{-2A(y)} \eta_{\mu\nu} dx^{\mu} dx^{\nu} + dy^2$$

$$\lim_{z\to\infty}y(z)\equiv y_s \mp \frac{1}{k\nu}\Gamma(0,\tfrac{2}{3}(\mu z_0)^{\nu})$$
 Finite

Pirsa: 10050014 Page 917/136

vitch to y

$$y(z) = \frac{1}{k\nu} \left[\Gamma(0, \frac{2}{3}(\mu z_0)^{\nu}) - \Gamma(0, \frac{2}{3}(\mu z)^{\nu}) \right]$$

w line element

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^
u + dy^2$$

$$\lim_{z\to\infty}y(z)\equiv y_s = \frac{1}{k\nu}\Gamma(0,\frac{2}{3}(\mu z_0)^{\nu})$$

Pirsa: 10050014

Finite

vitch to y

$$y(z) = \frac{1}{k\nu} \Big[\Gamma(0, \frac{2}{3}(\mu z_0)^{\nu}) - \Gamma(0, \frac{2}{3}(\mu z)^{\nu}) \Big]$$

w line element

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^
u + dy^2$$

$$\lim_{z\to\infty}y(z)\equiv y_s \mp \frac{1}{k\nu}\Gamma\big(0,\tfrac{2}{3}(\mu z_0)^\nu\big)$$
 Finite

Pirsa: 10050014 Page 919/13

Singularity implies boundary

Pirsa: 10050014 Page 920/1362

Singularity implies boundary

Pirsa: 10050014 Page 921/1362

- Singularity implies boundary
- Boundary implies boundary terms

Pirsa: 10050014 Page 922/1362

- Singularity implies boundary
- Boundary implies boundary terms

Pirsa: 10050014 Page 923/1362

- Singularity implies boundary
- Boundary implies boundary terms
- Boundary terms mean equations of motion may change

Pirsa: 10050014 Page 924/1362

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Pirsa: 10050014 Page 925/1362

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Pirsa: 10050014 Page 926/136

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Pirsa: 10050014 Page 927/1362

- Singularity implies boundary
- Boundary implies boundary terms
- Boundary terms mean equations of motion may change
- Need to ensure boundary terms vanish
 - Non-vanishing implies non-zero 4D cosmological constant
 - 4D cosmological constant means no flat spacetime

Pirsa: 10050014 Page 928/136

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Pirsa: 10050014 Page 929/13

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Pirsa: 10050014 Page 930/13

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Pirsa: 10050014 Page 931/13

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Pirsa: 10050014 Page 932/136

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Pirsa: 10050014 Page 933/13

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Pirsa: 10050014 Page 934/136

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Pirsa: 10050014 Page 935/13

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Pirsa: 10050014 Page 936/136

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Pirsa: 10050014 Page 937/1362

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Pirsa: 10050014 Page 938/13

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Pirsa: 10050014 Page 939/13

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Pirsa: 10050014 Page 940/13

If-consistency condition [Cabrer et al.]

superpotential grows asymptotically slower than $e^{2\eta/\sqrt{3}}$

symptotic form for superpotential:

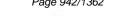
$$W \sim \frac{1}{2\sqrt{3}} k \nu \eta e^{\eta/\sqrt{3}}$$

If-consistency condition [Cabrer et al.]

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symptotic form for superpotential:

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Pirsa: 10050014 Page 957/13

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symptotic for for superpotential:

$$w_{2\sqrt{3}}k\nu\eta e^{\eta/\sqrt{3}}$$

If-consistency condition [Cabrer et al.]

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symptotic for for superpotential:

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symptotic for for superpotential:

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Achieving the Hierarchy

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Achieving the Hierarchy

• Need to achieve $\mu/k \sim 10^{-16}$

- Need to achieve $\mu/k \sim 10^{-16}$
- What sets μ/k ?
- Consider:
 - \bullet μ sets scale where scalar back-reaction strong
 - Must fix field at one location
 - Boundary condition on UV brane fixes field

Dogwood & Potestiller

Boundaly conditions require --- =

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Boundary potential

 $u_{uv} = W_{t+e}[-w \dot{W}_{t+e}]_{uv} - u_{e}[-w \dot{W}_{t+$

Boundary conditions require m = 1/2

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Boundary potential

 $\mathbf{u}_{\mathbf{v}} = \mathbf{W}_{\mathbf{v},\mathbf{v}} = \mathbf{W}_{\mathbf{v},\mathbf{v}}$

Boundary conditions require - - -

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Boundary conditions require in = 115

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Boundary potential

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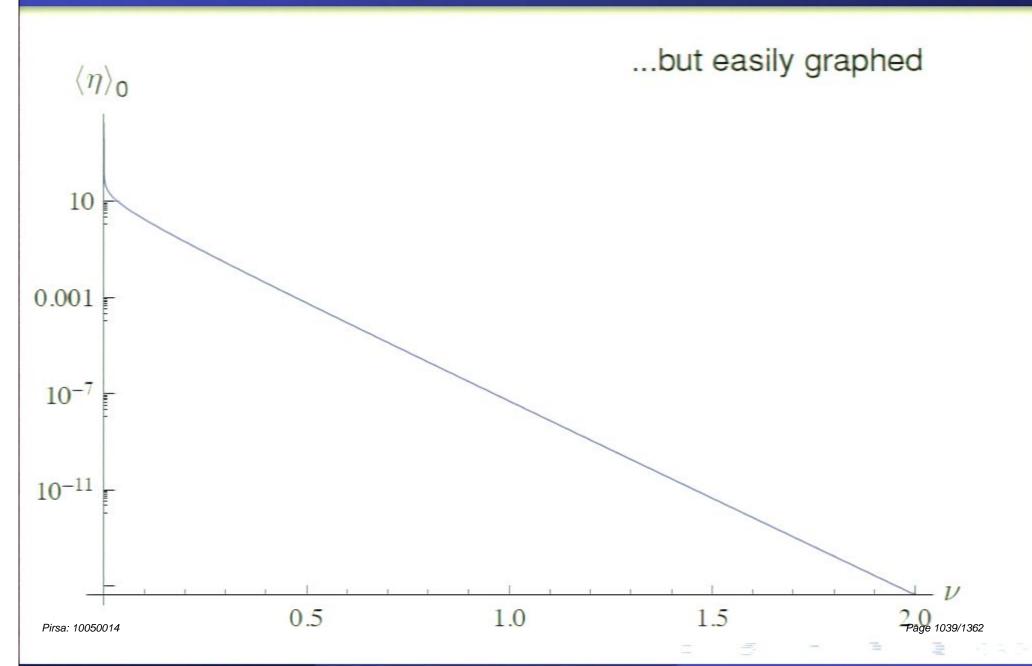
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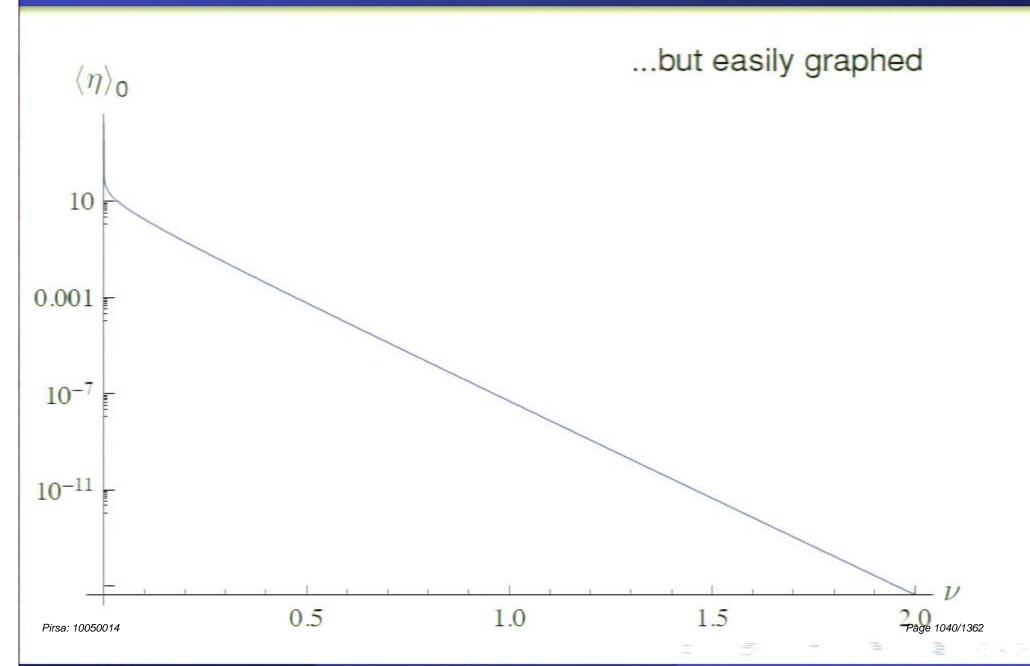
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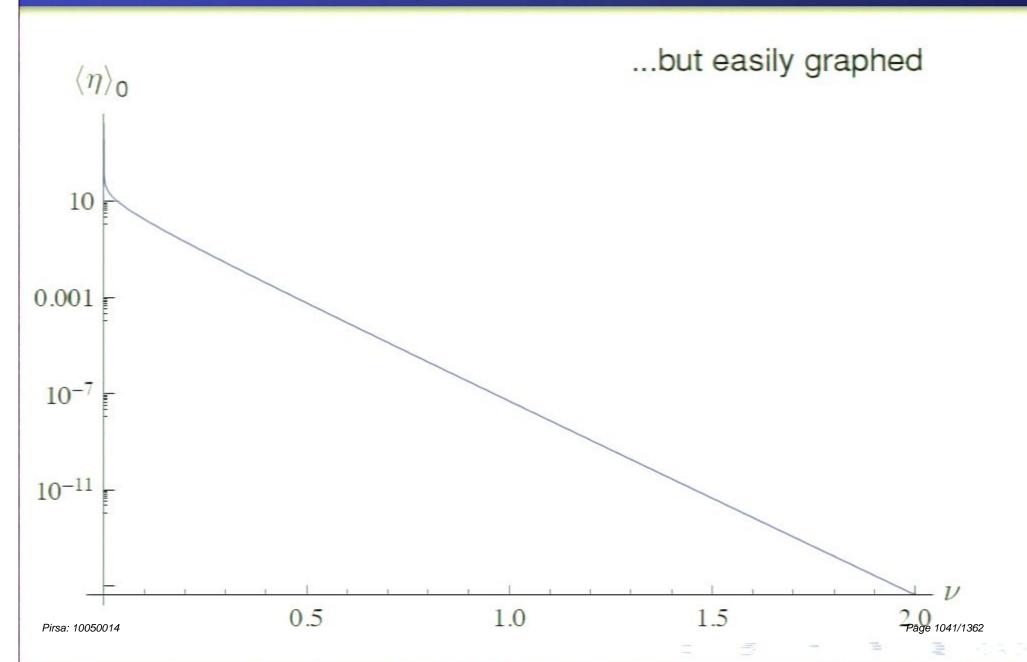
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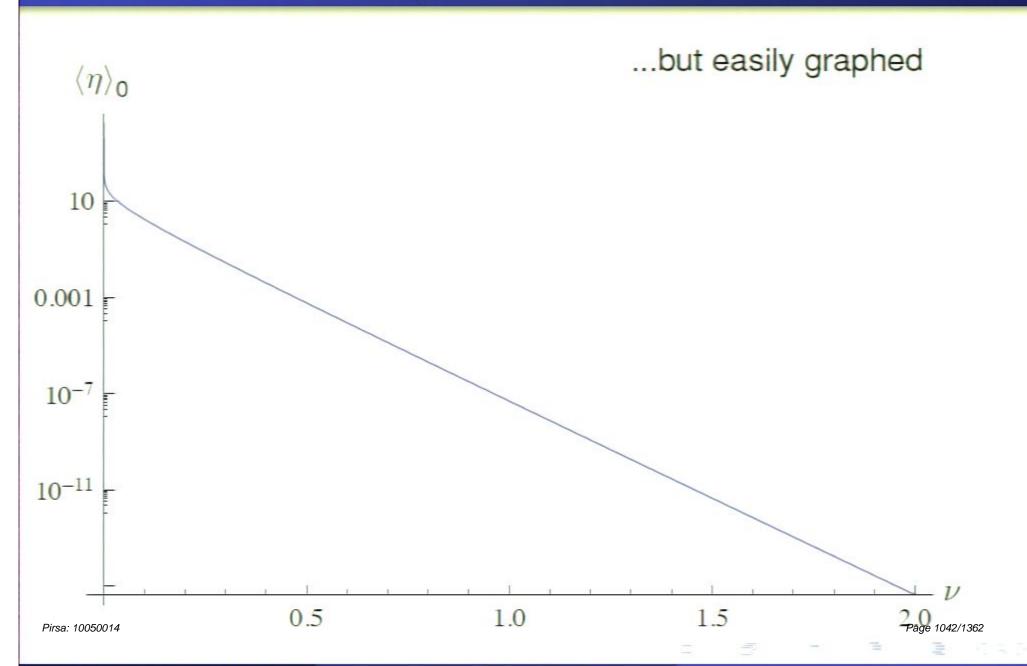
$$\eta_{0} = \pm \sqrt{3} \left(\frac{\nu + 1}{\nu} \right) \left[\sqrt{\frac{2}{3} \frac{\nu}{\nu + 1}} \left(\frac{\mu}{k} \right)^{\nu} + \left(\frac{2}{3} \frac{\nu}{\nu + 1} \left(\frac{\mu}{k} \right)^{\nu} \right)^{2} + \sinh^{-1} \sqrt{\frac{2}{3} \frac{\nu}{\nu + 1}} \left(\frac{\mu}{k} \right)^{\nu} \right]$$

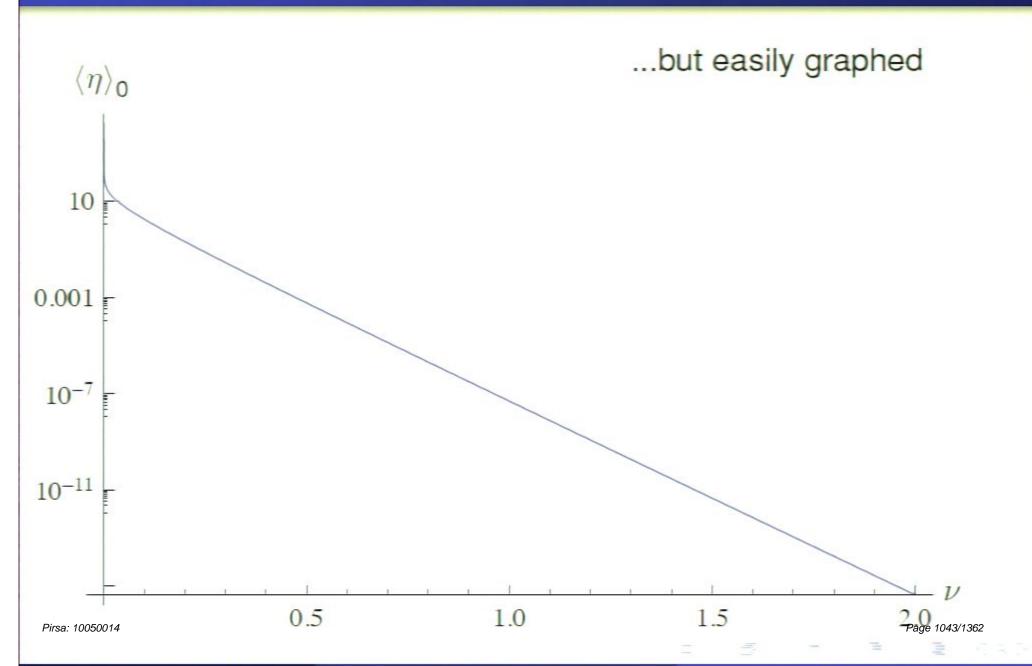
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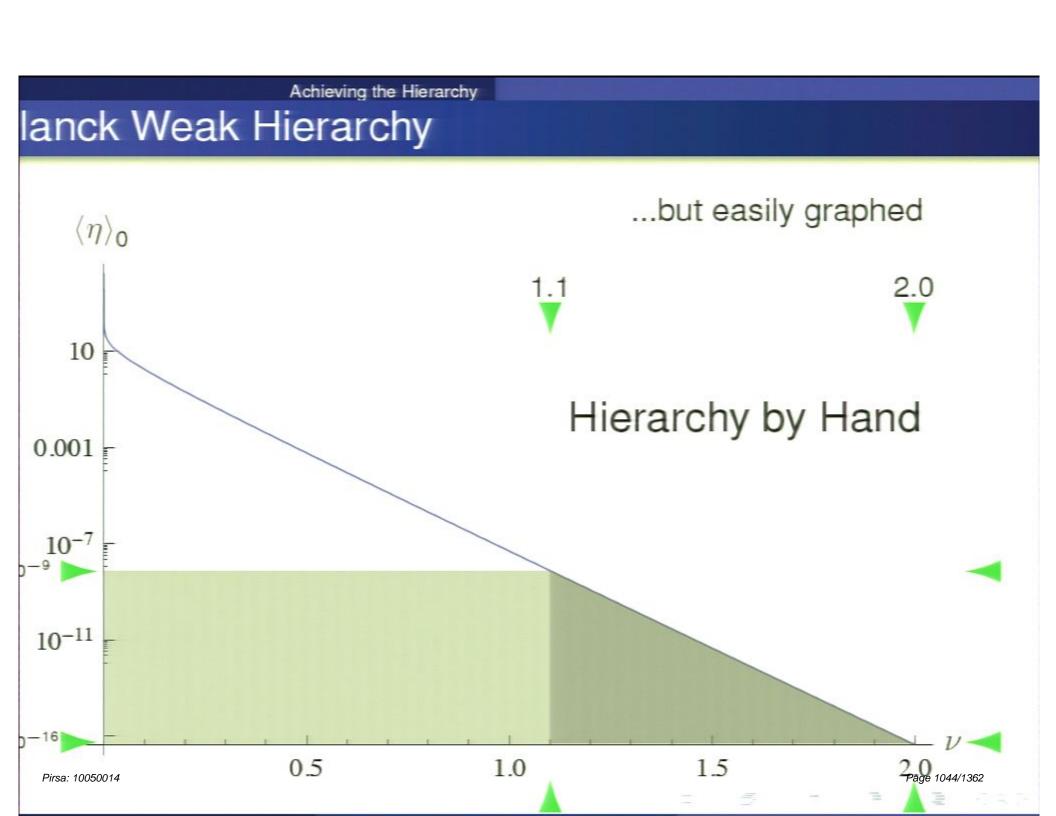


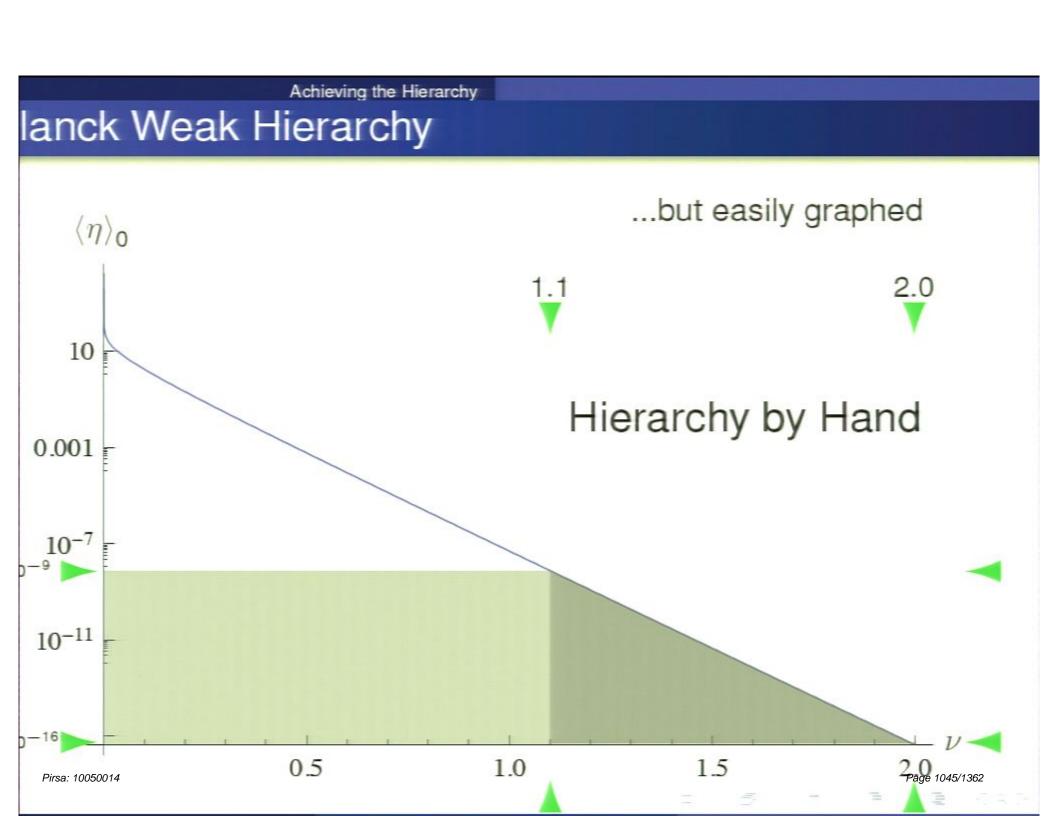


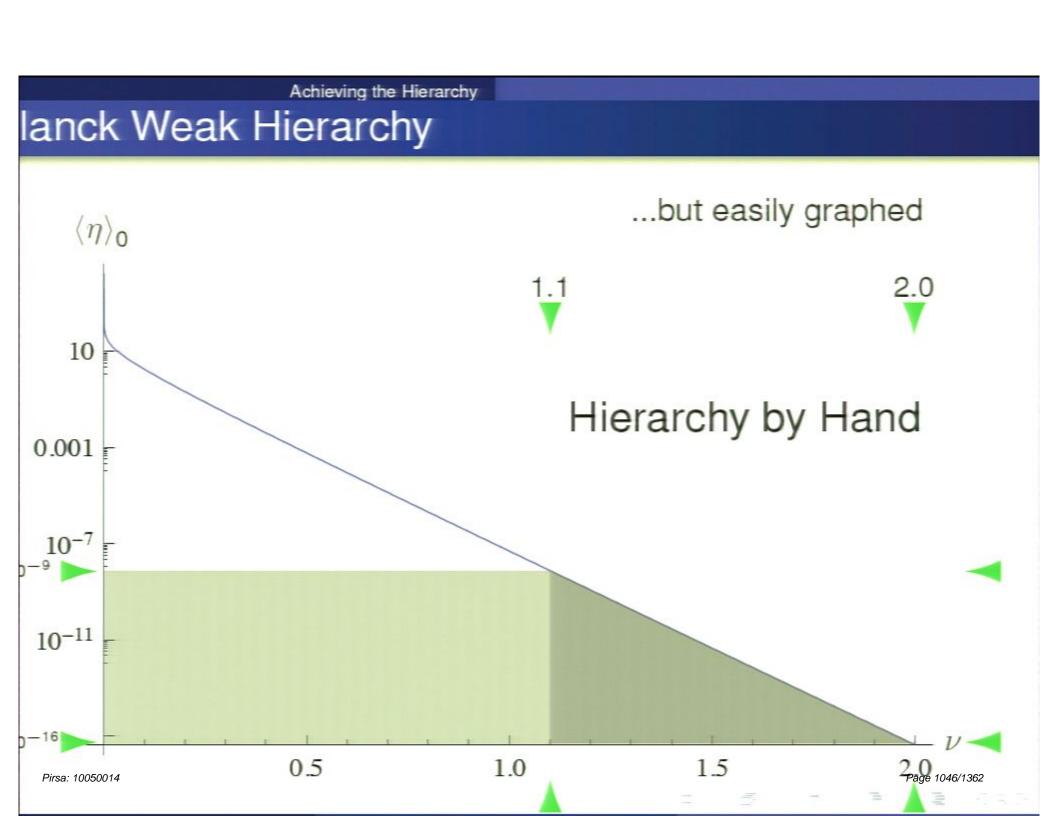


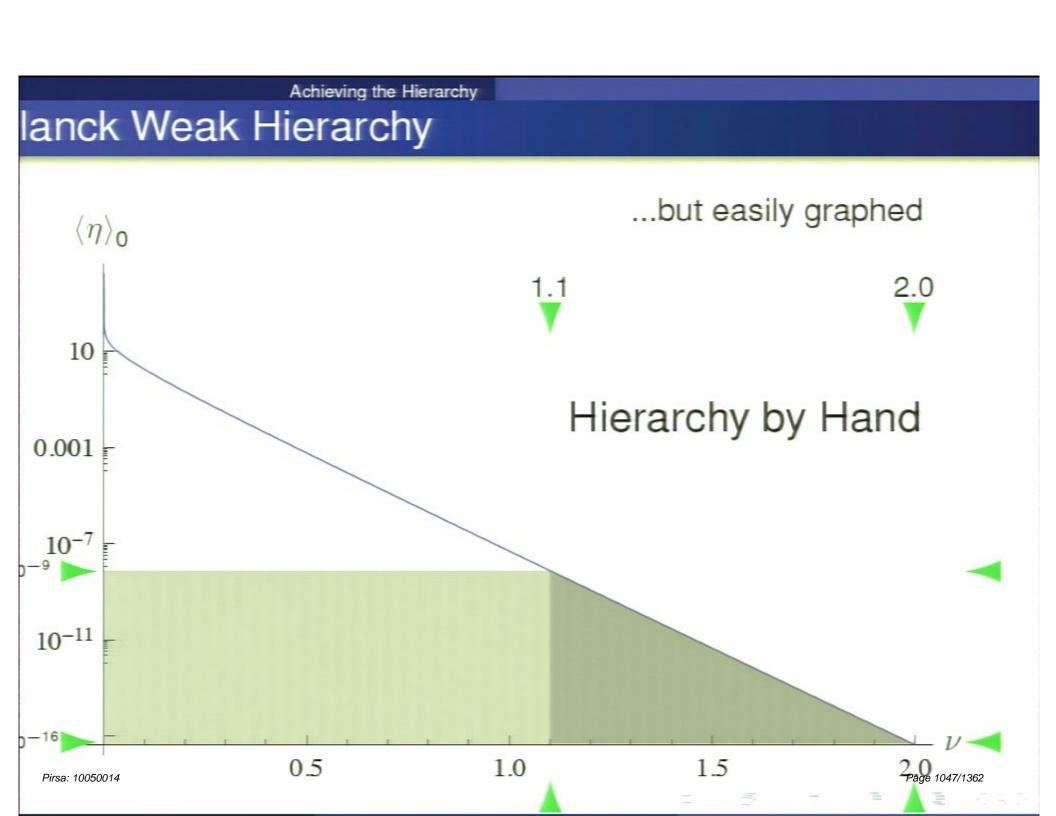


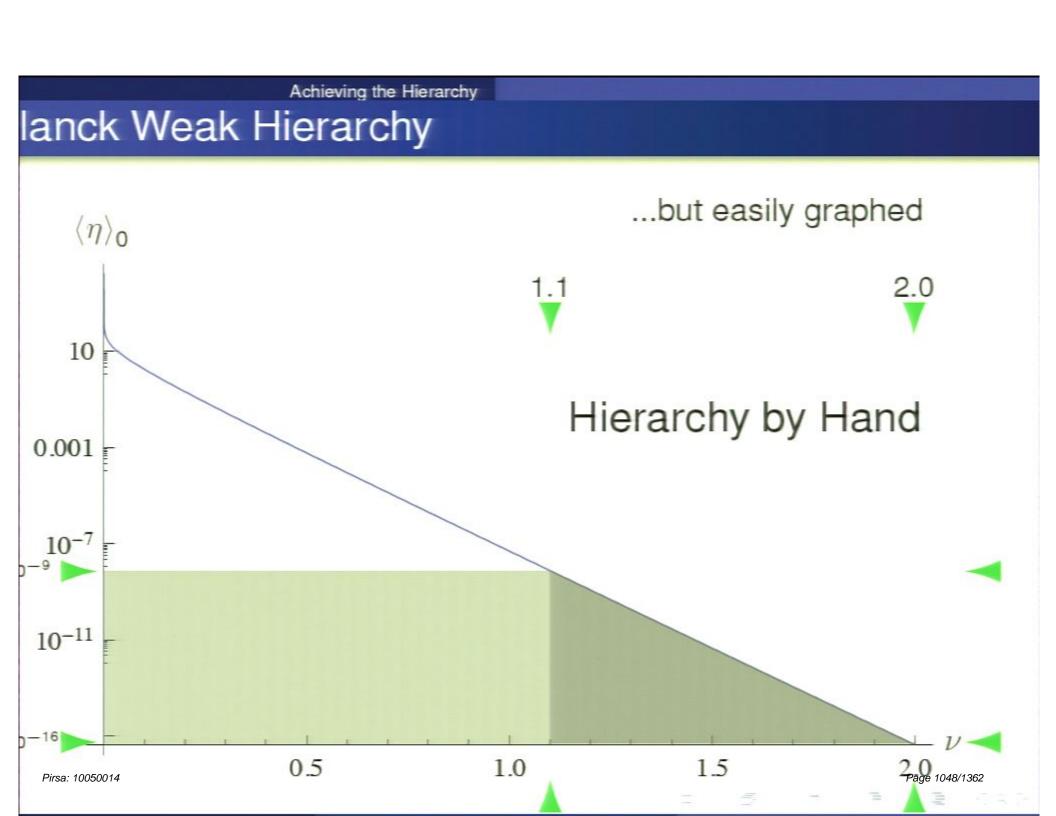


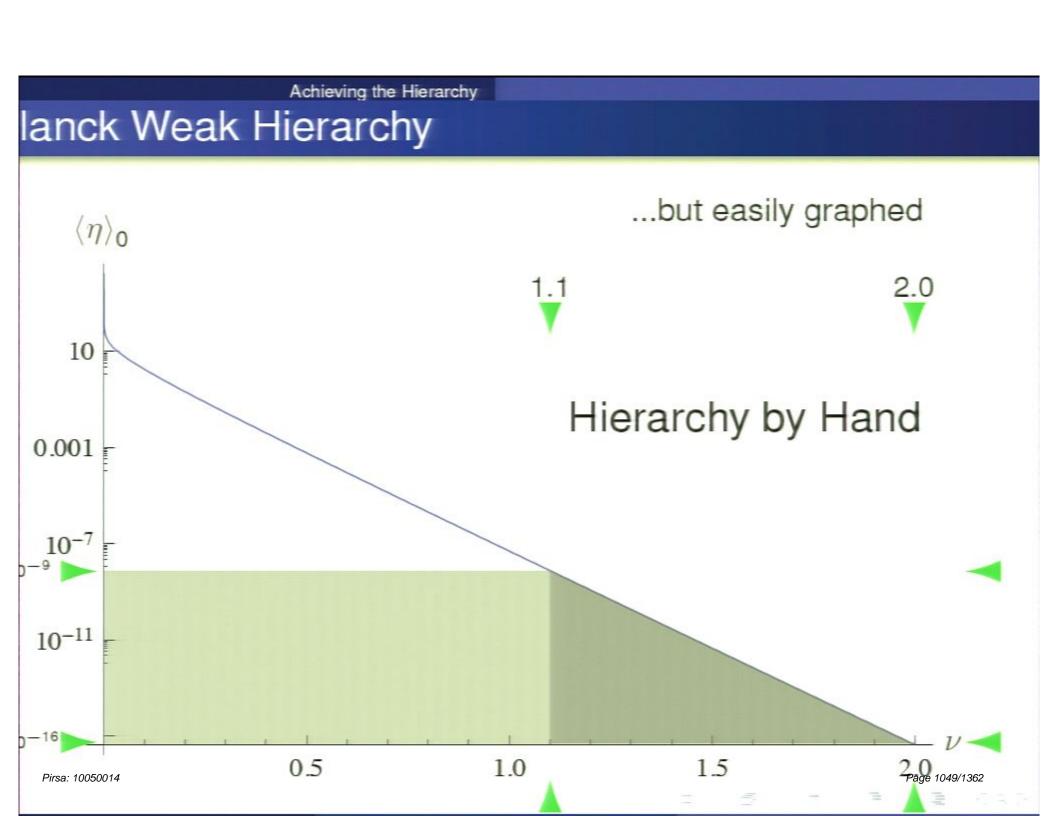


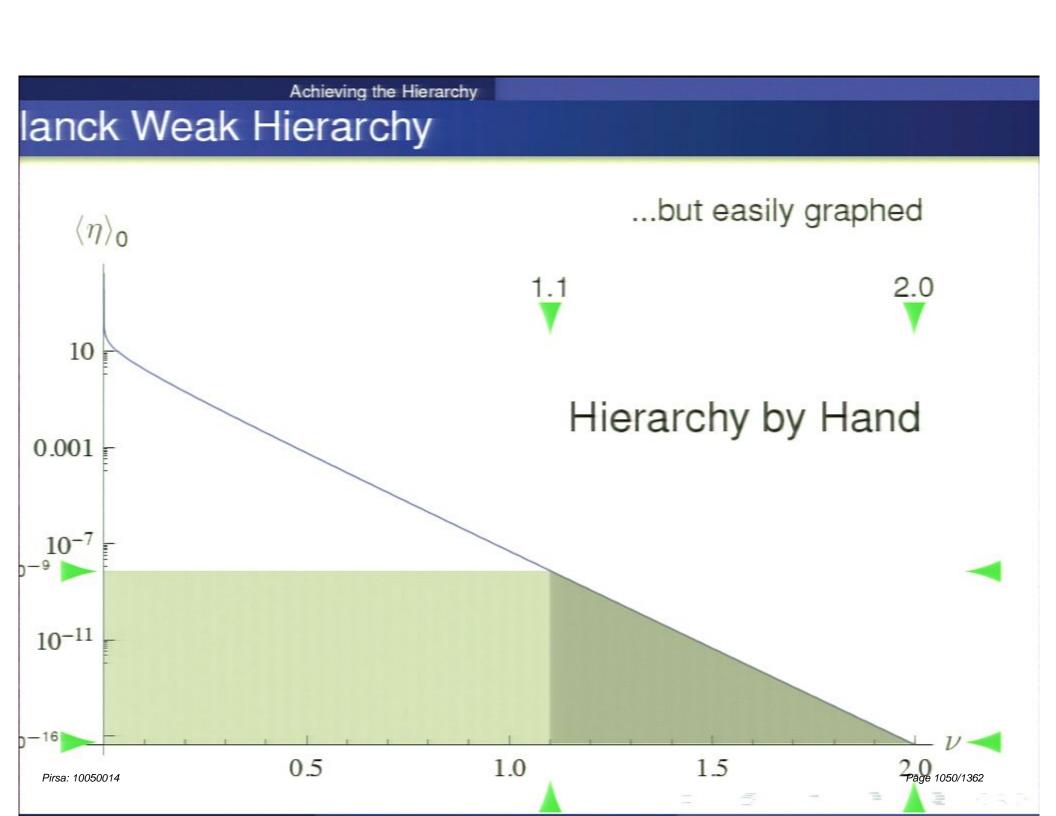


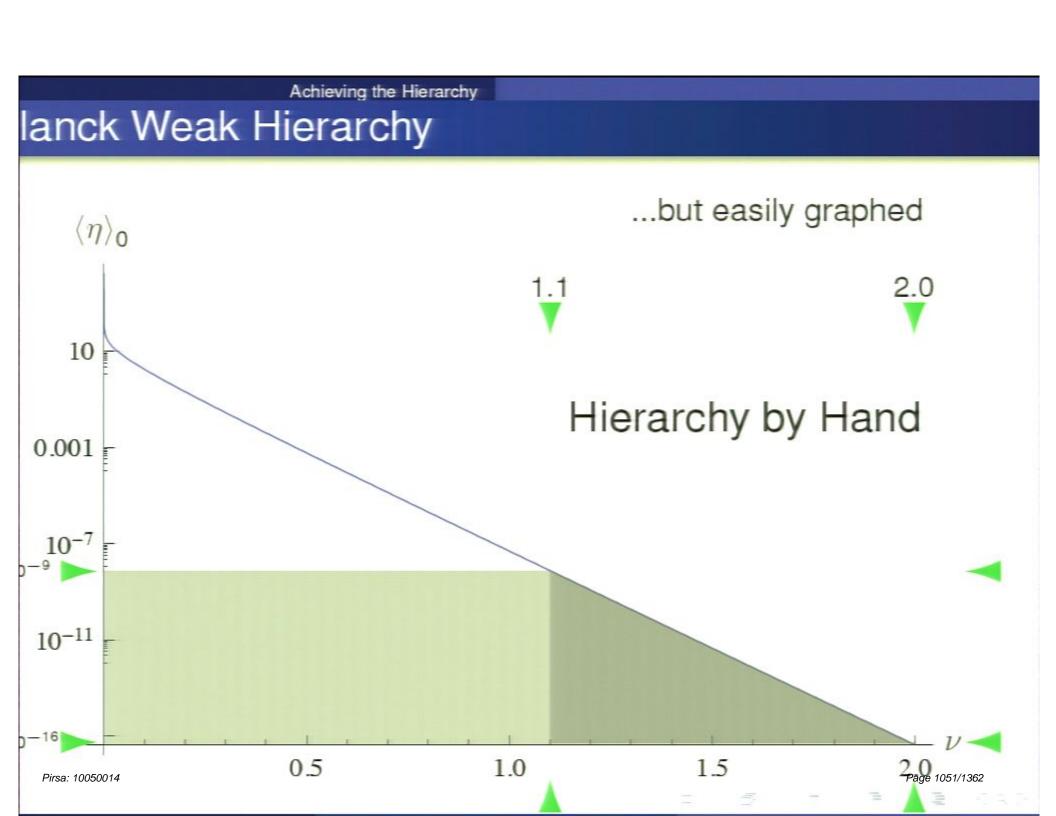


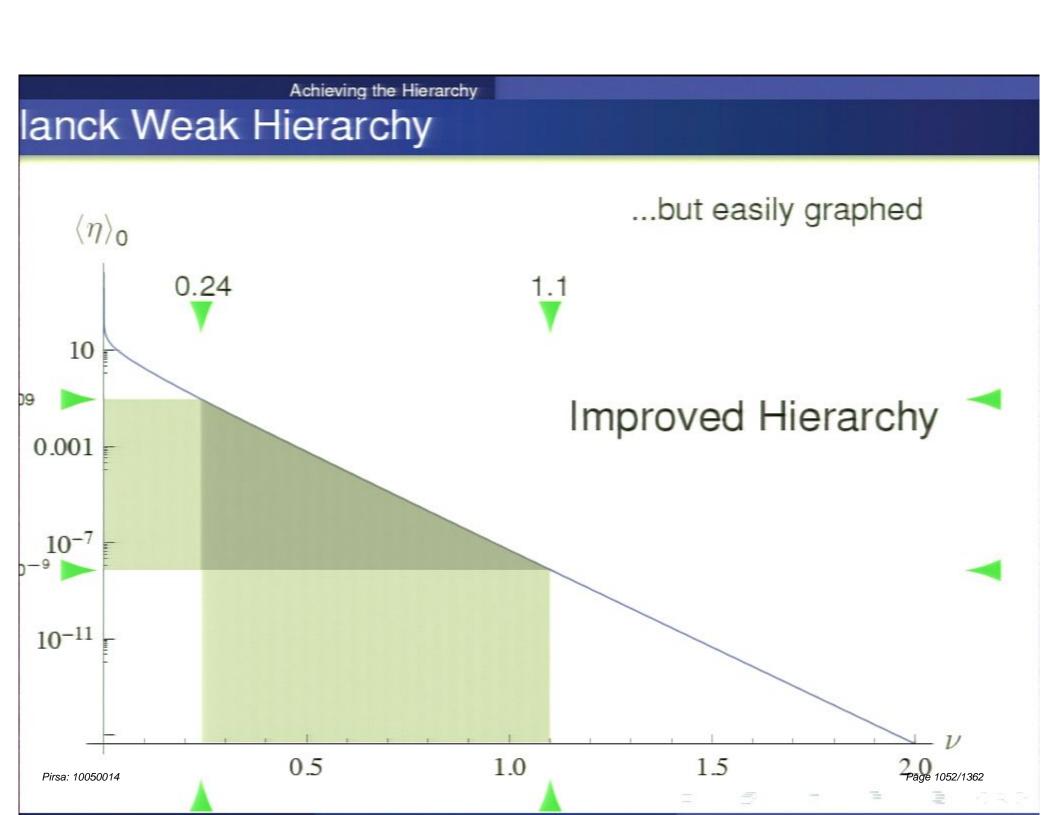


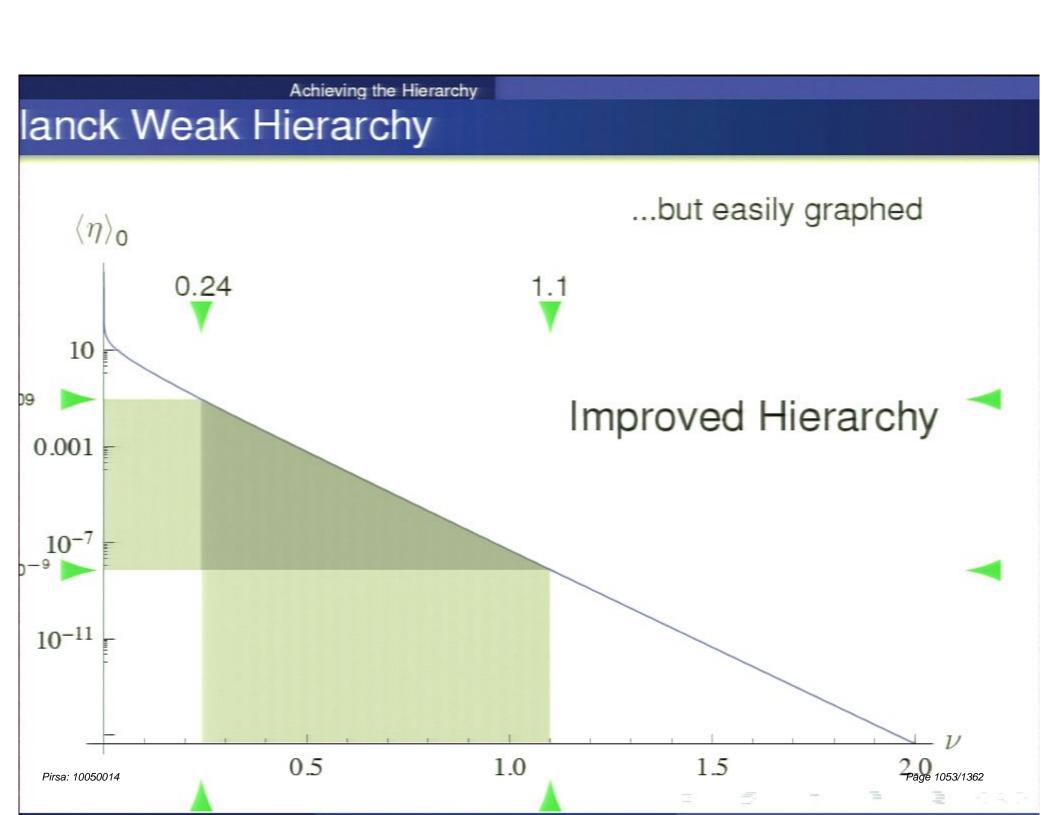


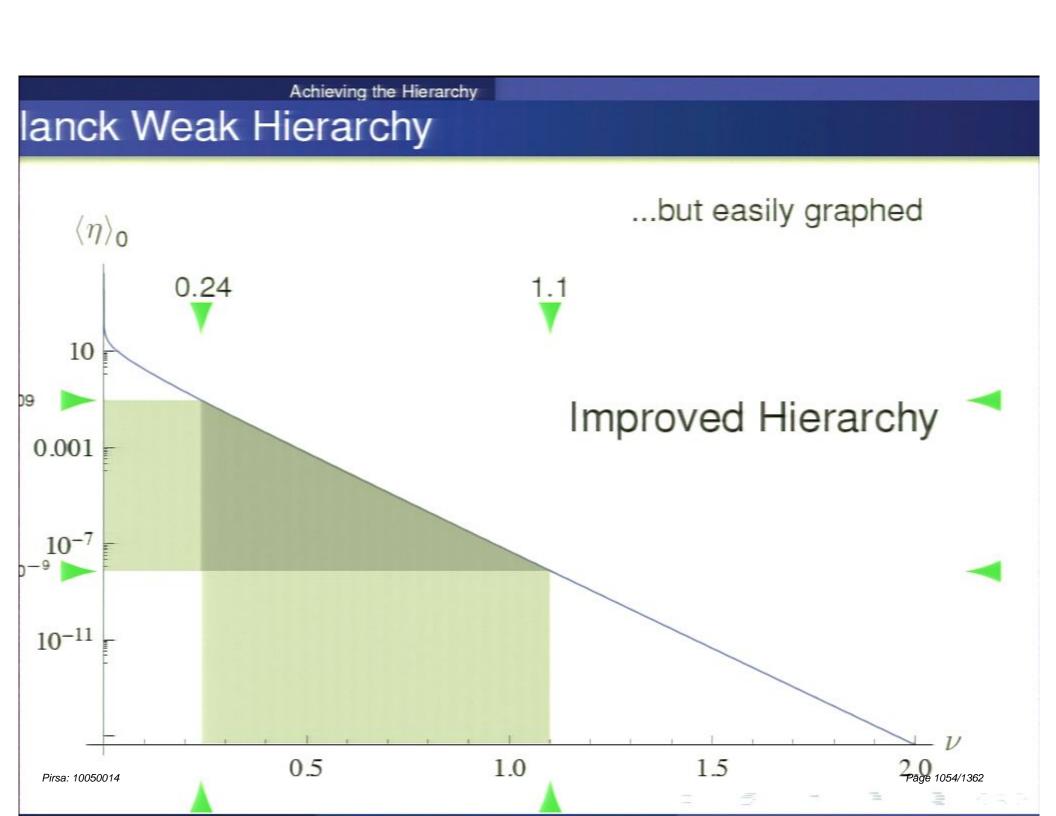


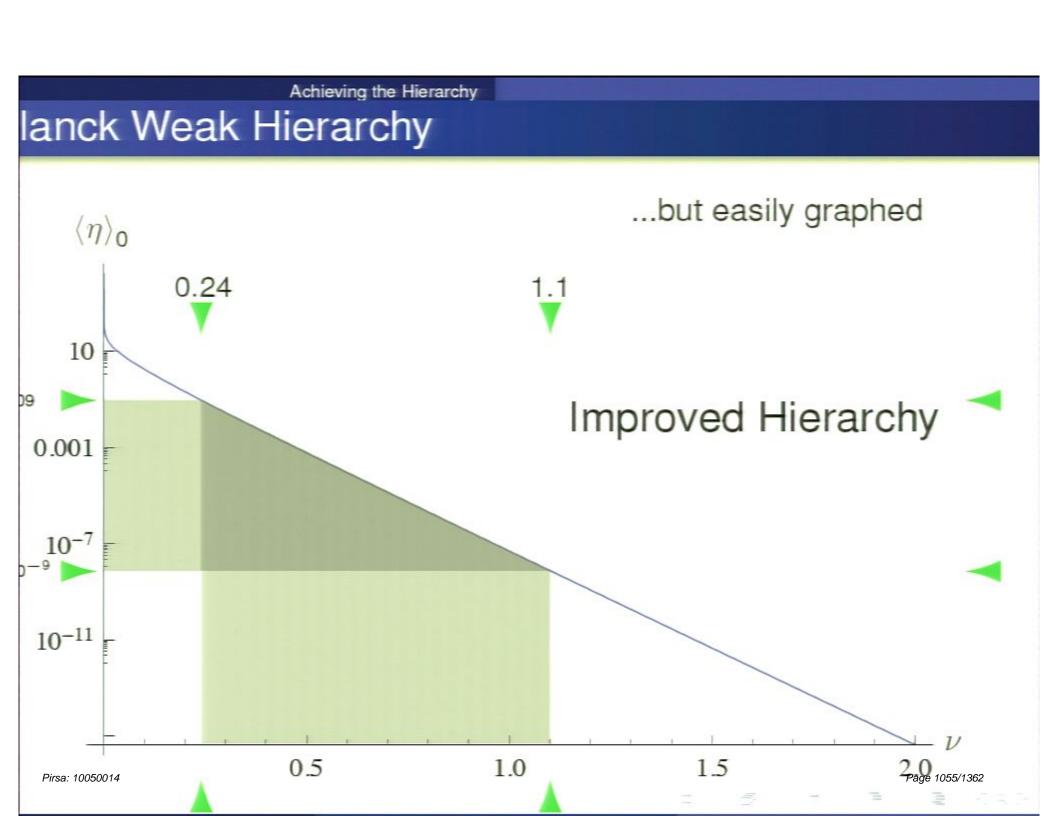


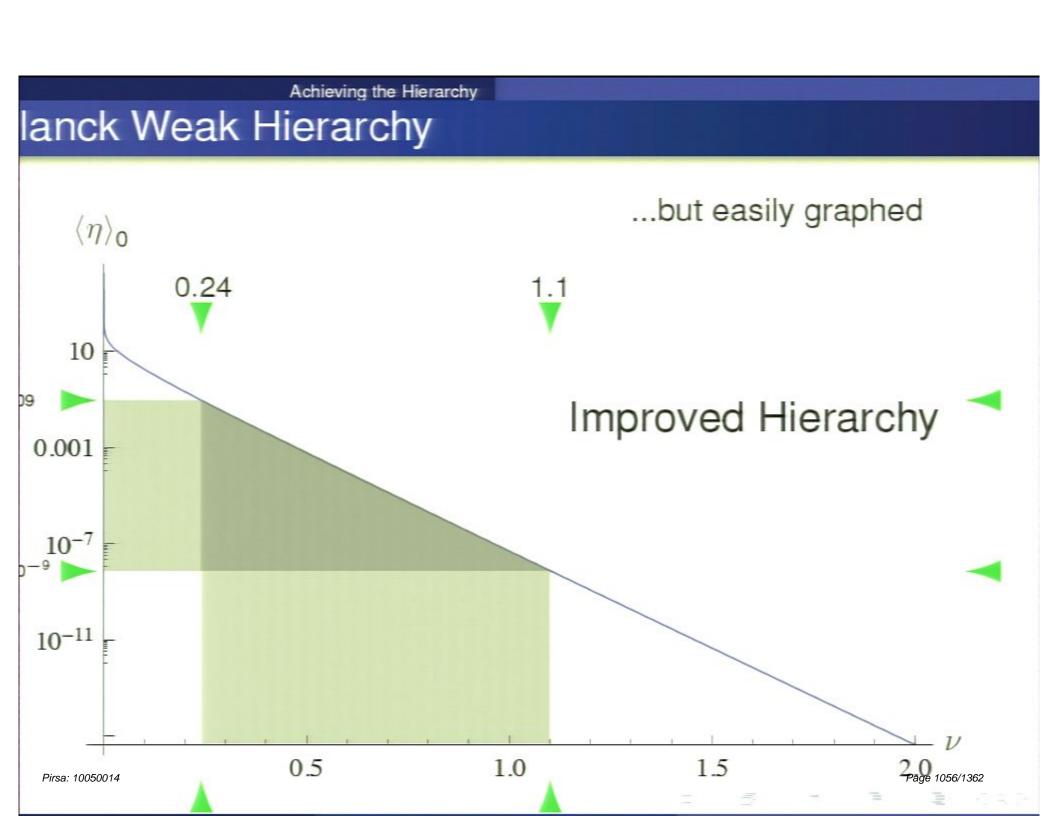


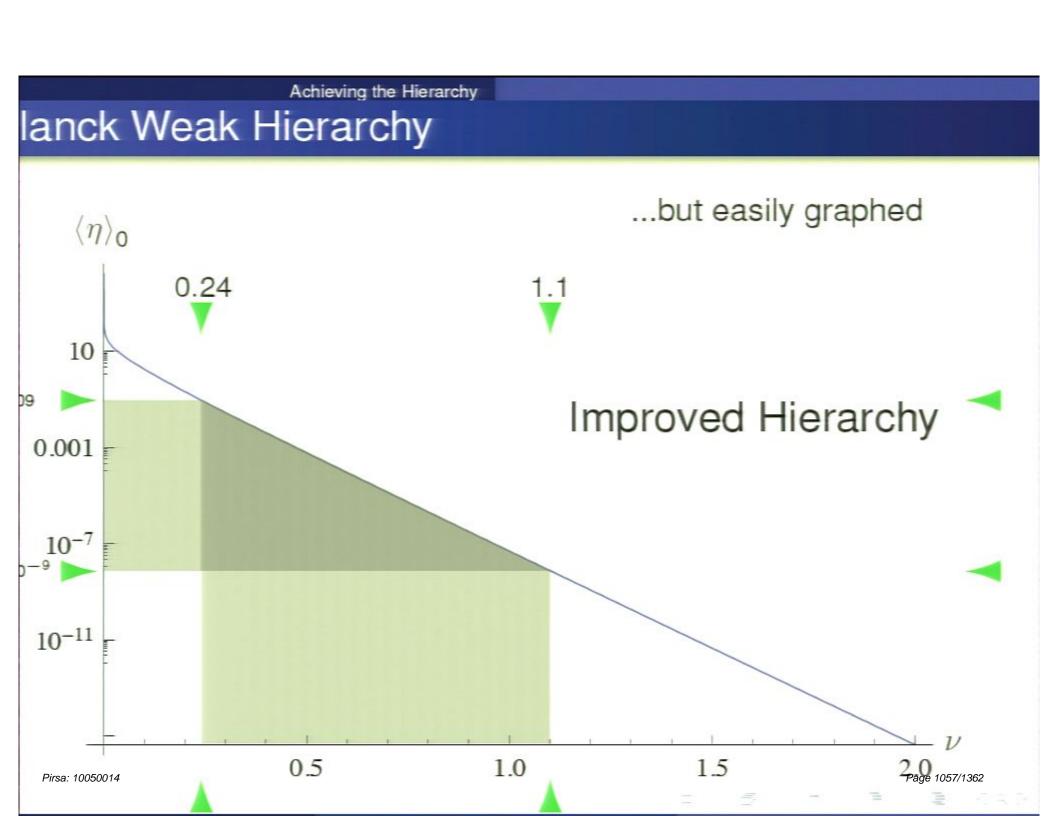


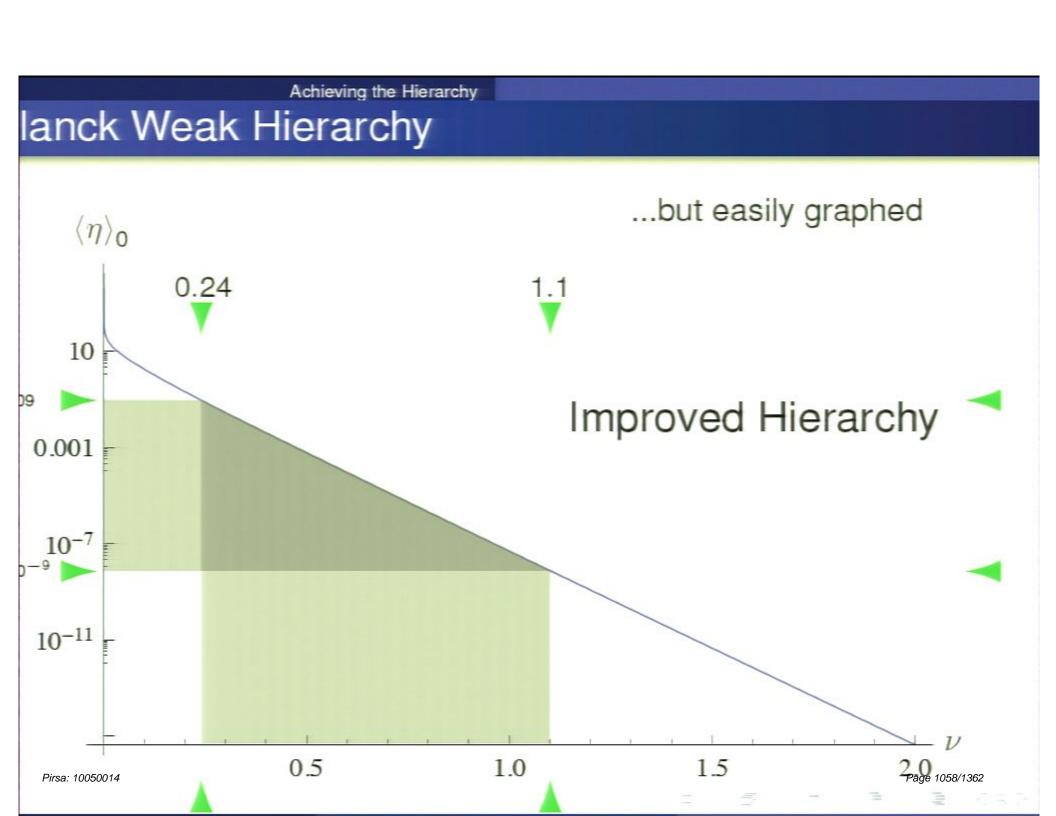


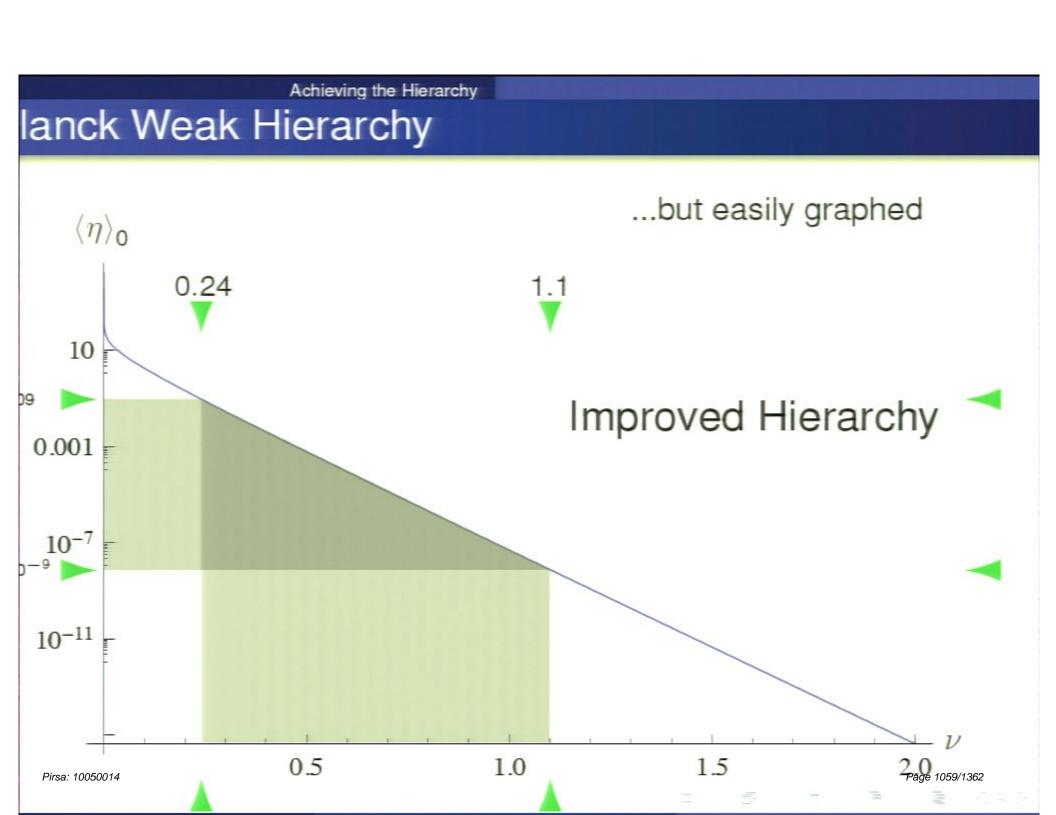


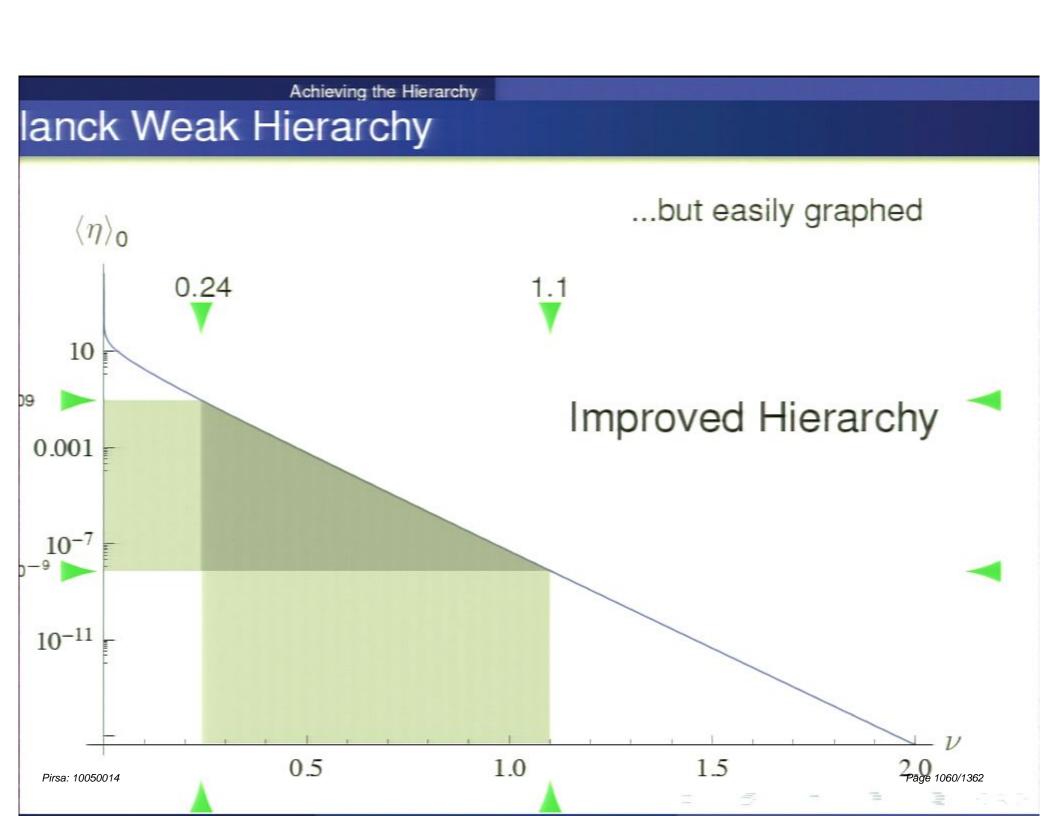


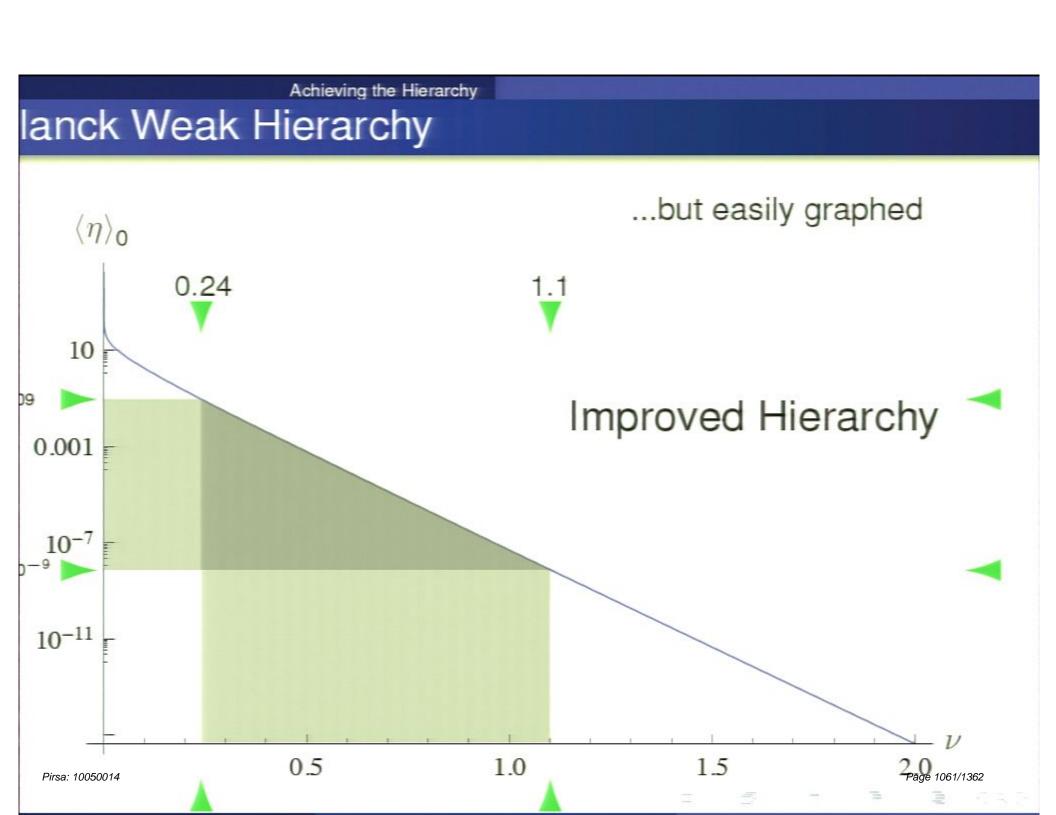


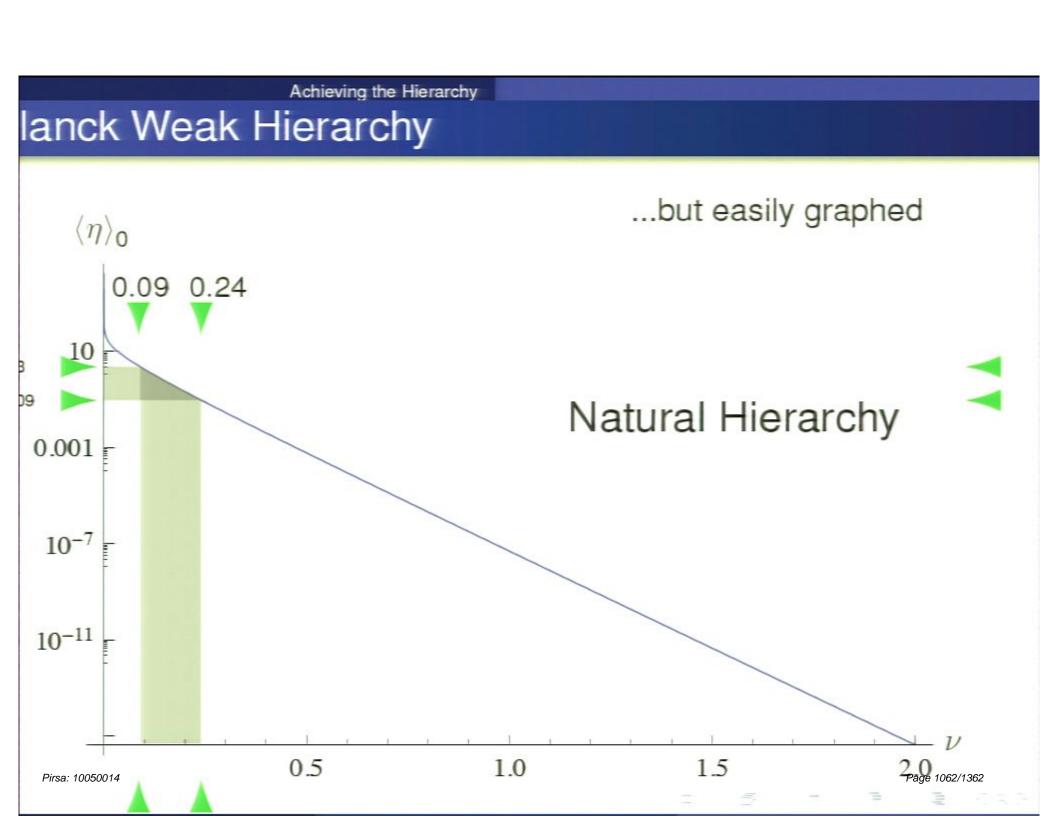


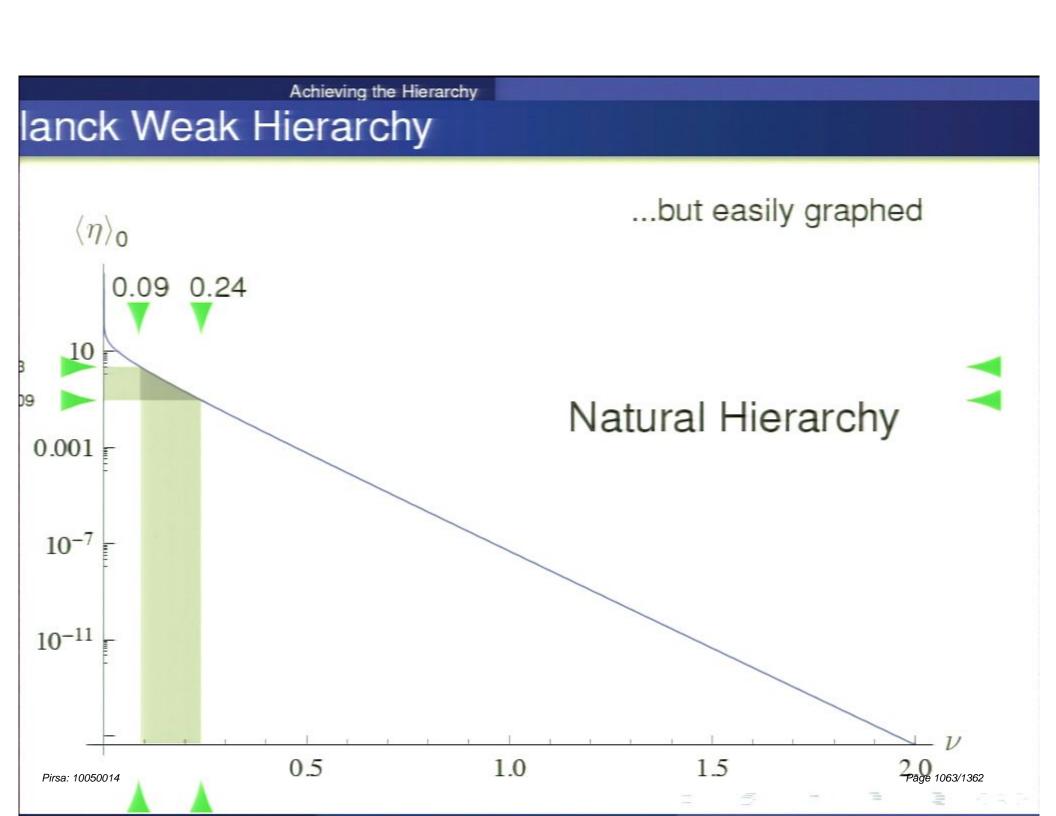


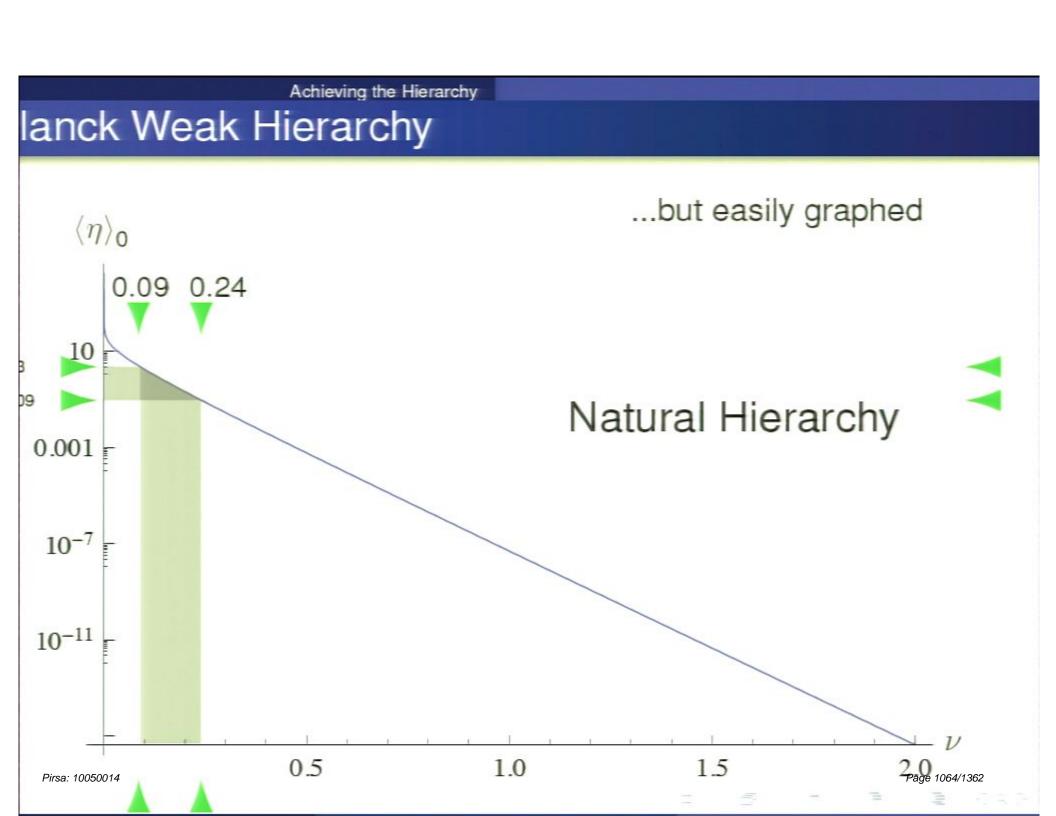


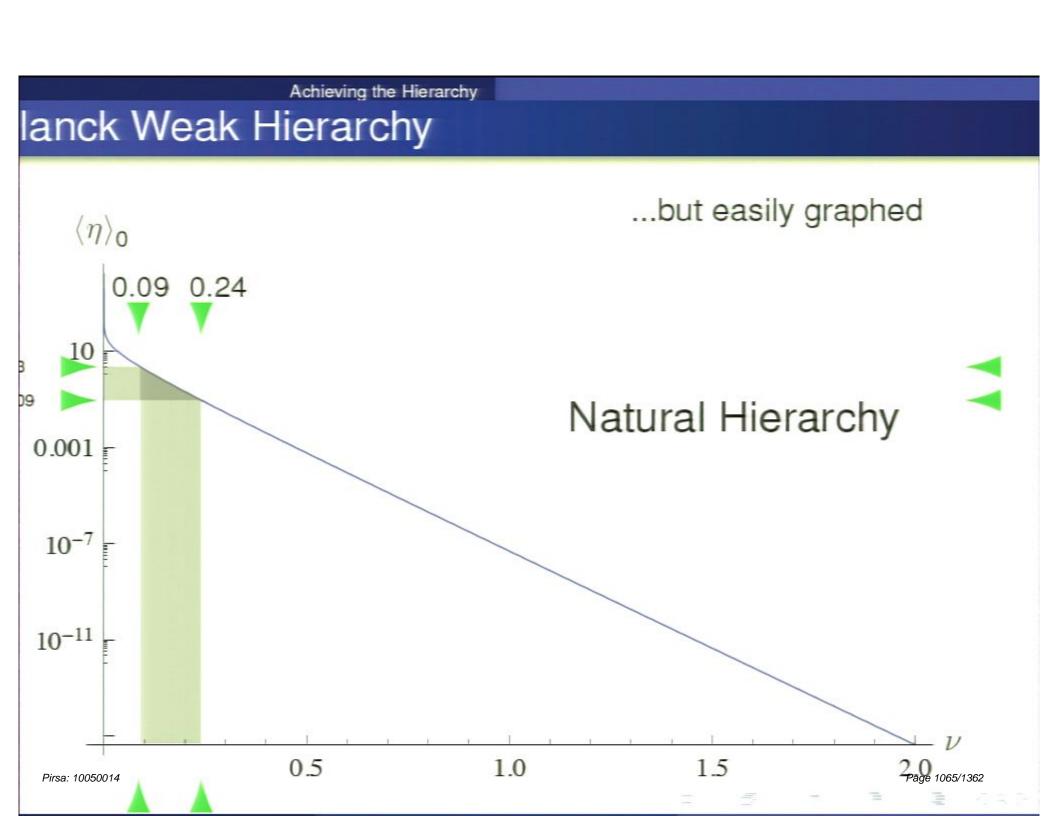


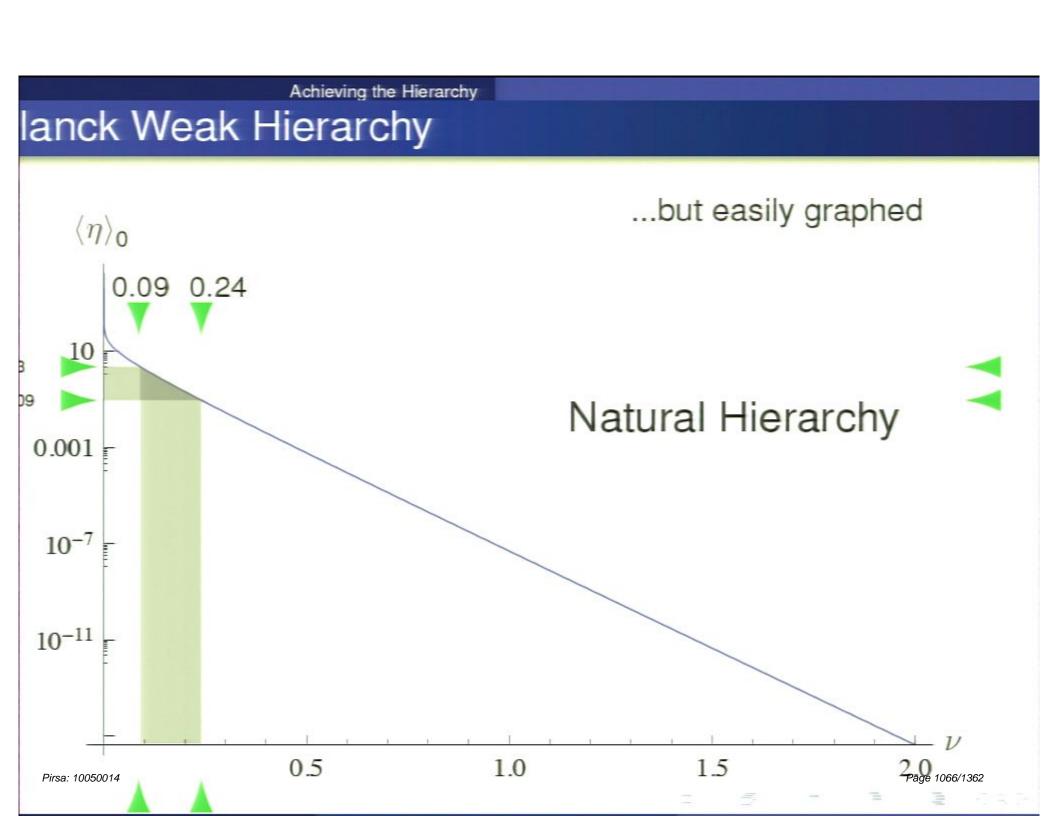


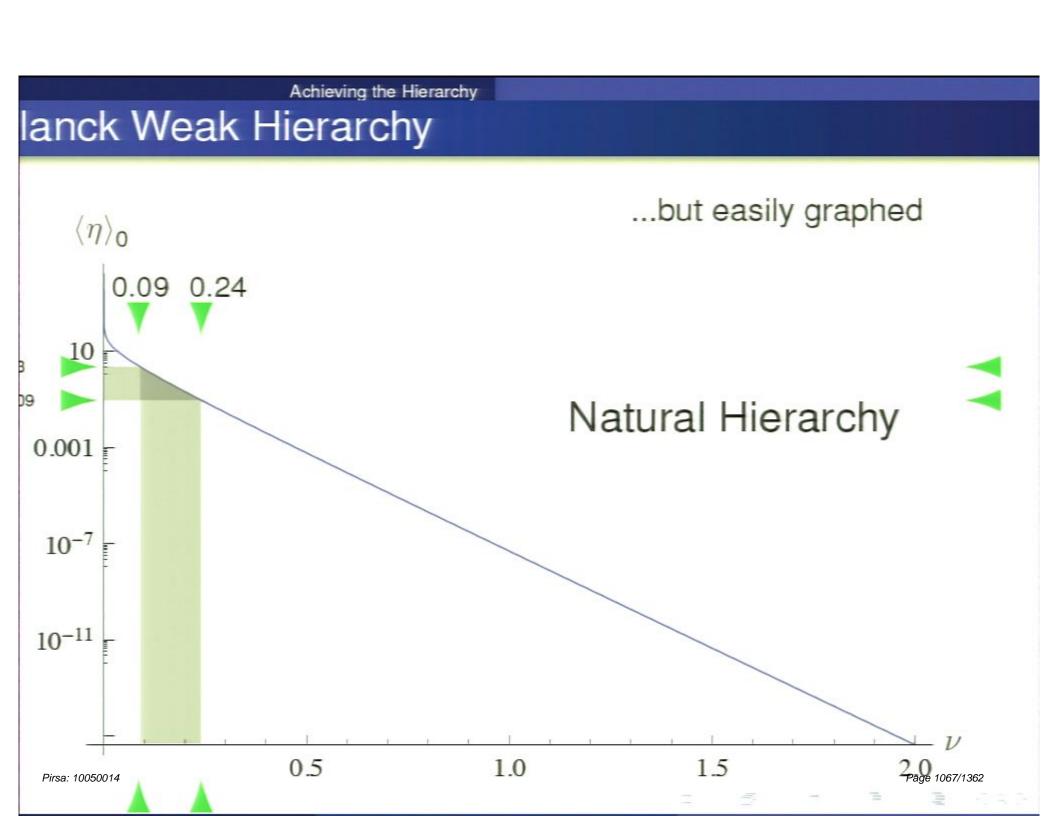


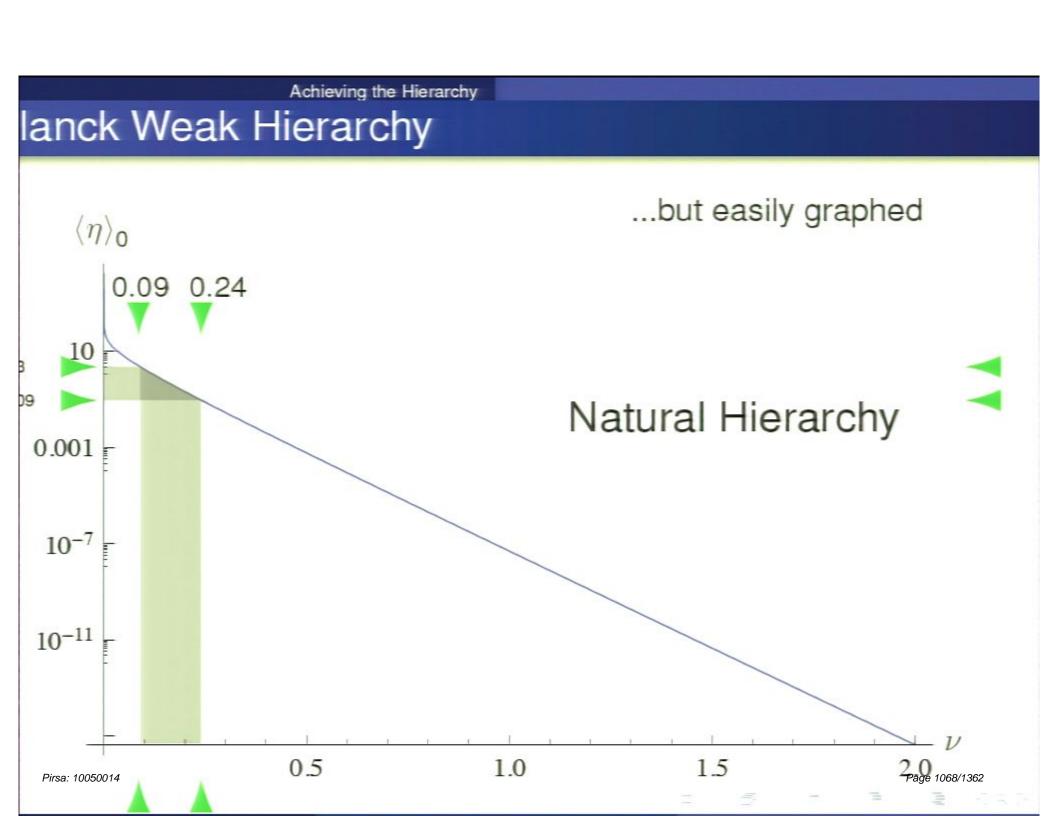


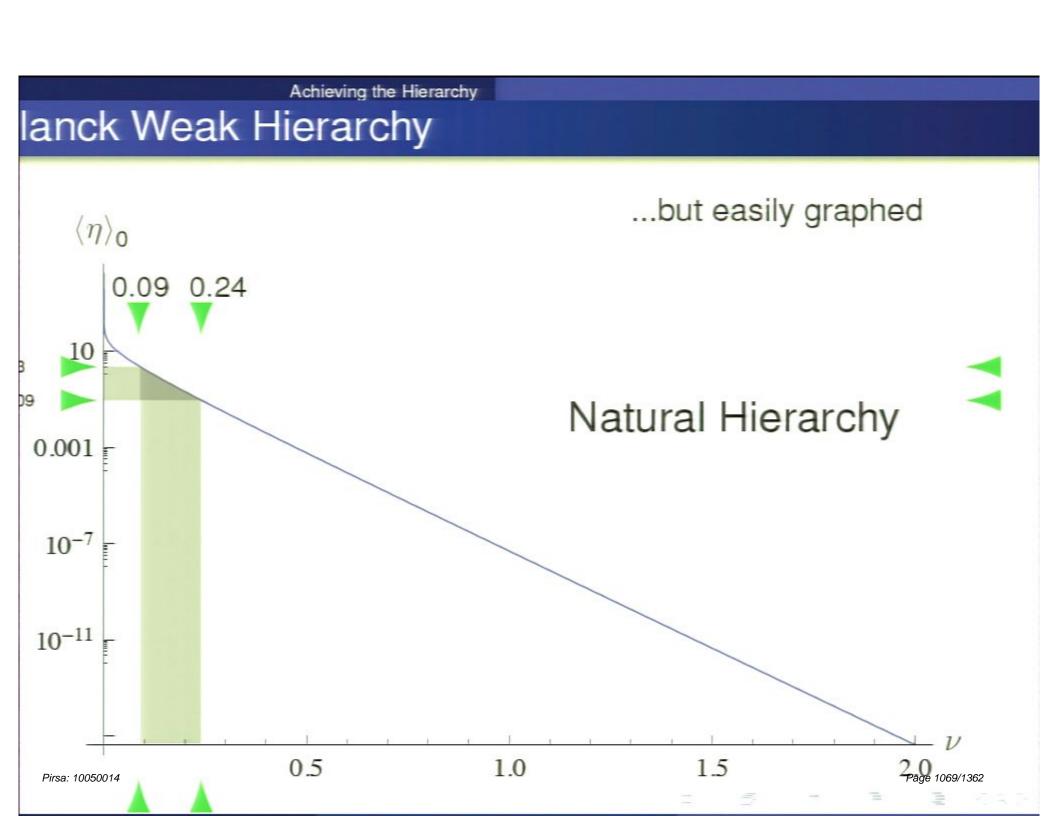


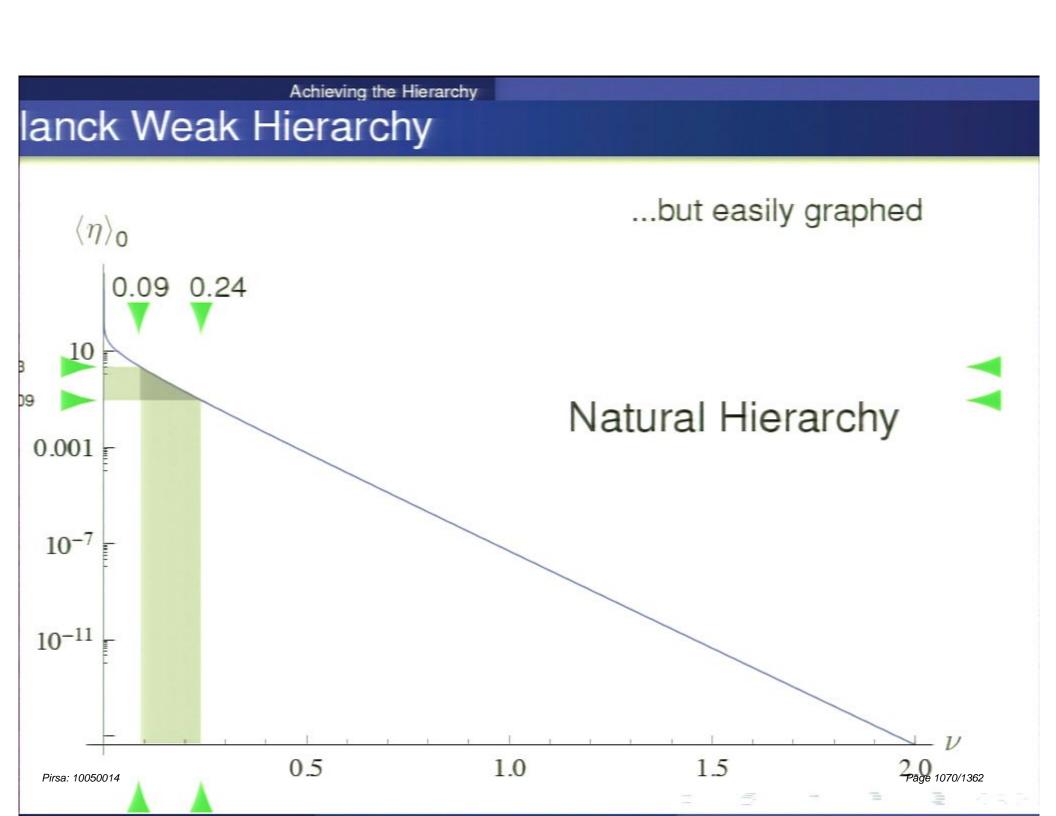












The value of the field at the UV brane is

$$\eta_{0} = \pm \sqrt{3} \left(\frac{\nu + 1}{\nu} \right) \left[\sqrt{\frac{2}{3} \frac{\nu}{\nu + 1}} \left(\frac{\mu}{k} \right)^{\nu} + \left(\frac{2}{3} \frac{\nu}{\nu + 1} \left(\frac{\mu}{k} \right)^{\nu} \right)^{2} + \sinh^{-1} \sqrt{\frac{2}{3} \frac{\nu}{\nu + 1}} \left(\frac{\mu}{k} \right)^{\nu} \right]$$

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$$\left. + \sinh^{-1} \sqrt{\frac{2}{3} \frac{\nu}{\nu+1}} \left(\frac{\mu}{k} \right)^{\nu} \right]$$

Not easily inverted...

Pirsa: 10050014 Page 10

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Not easily inverted...

Pirsa: 10050014 Page 1073/136

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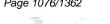
Pirsa: 10050014 Pag

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$$\left. + \sinh^{-1} \sqrt{\frac{2}{3} \frac{\nu}{\nu+1}} \left(\frac{\mu}{k} \right)^{\nu} \right]$$

Not easily inverted...

Pirsa: 10050014 Page 1078/13

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Not easily inverted...

Pirsa: 10050014 Page 1079/136

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Not easily inverted...

Pirsa: 10050014 Page 1080/13

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Not easily inverted...

Pirsa: 10050014 Page 1081/136

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Not easily inverted...

Pirsa: 10050014 Page 1082/136

The value of the field at the UV brane is

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Not easily inverted...

Pirsa: 10050014 Page 1083/13

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Not easily inverted...

Pirsa: 10050014 Page 1086/136

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Not easily inverted...

Pirsa: 10050014 Page 1087/1

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Pirsa: 10050014 Page 1088/136

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Pirsa: 10050014 Page 1089/136

an also ask how sensitive $\langle \eta \rangle_0$ is to μ/k (and vice-versa).

% change in $\langle \eta \rangle_0$ for 1% change in weak scale

 $\sim 1/4$ 0.1% (fairly robust)

 $\leq \nu \leq$ 3 1% (robust)

>> 1 very sensitive to variation

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ok at potential

$$V(\eta) = -12k^2 - k^2\nu \left(1 - \frac{\nu}{8}\right)\eta^2 + \cdots$$

ves η 's mass as

$$m_{\eta}^2 = -2k^2\nu\left(1 - \frac{\nu}{8}\right)$$

IS/CFT correspondence says operator dimension is

$$\Delta = 2 + \sqrt{4 + \frac{m_{\eta}^2}{k^2}} = 2 + \frac{1}{2}|4 - \nu|$$

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Pirsa: 10050014 Page 1112/13

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Pirsa: 10050014 Page 1113/13

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Pirsa: 10050014 Page 1114/13

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Pirsa: 10050014 Page 1115/13

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Pirsa: 10050014 Page 1117/136

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$$\Delta = 2 + \sqrt{4 + \frac{m_{\eta}^2}{k^2}} = 2 + \frac{1}{2}|4 - \nu|$$

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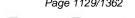
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perator Dimension

e breakdown is

Hierarchy by Hand
$$\nu > 1$$

$$\nu > 1$$

$$\Delta > \frac{5}{2}$$

Improved Hierarchy
$$\nu \sim 1$$
 $\Delta \sim \frac{5}{2}$

$$\nu \sim 1$$

$$\Delta \sim \frac{5}{2}$$

Natural Hierarchy
$$0 < \nu < 1$$
 $2 < \Delta < \frac{5}{2}$

$$0 < \nu < 1$$

$$2 < \Delta < \frac{5}{2}$$

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Pirsa: 10050014 Page 1142/13

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Pirsa: 10050014 Page 1147/136

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Pirsa: 10050014 Page 1151/13

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calar's Potential

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lanck Weak Hierarchy Robustness

an also ask how sensitive $\langle \eta \rangle_0$ is to μ/k (and vice-versa).

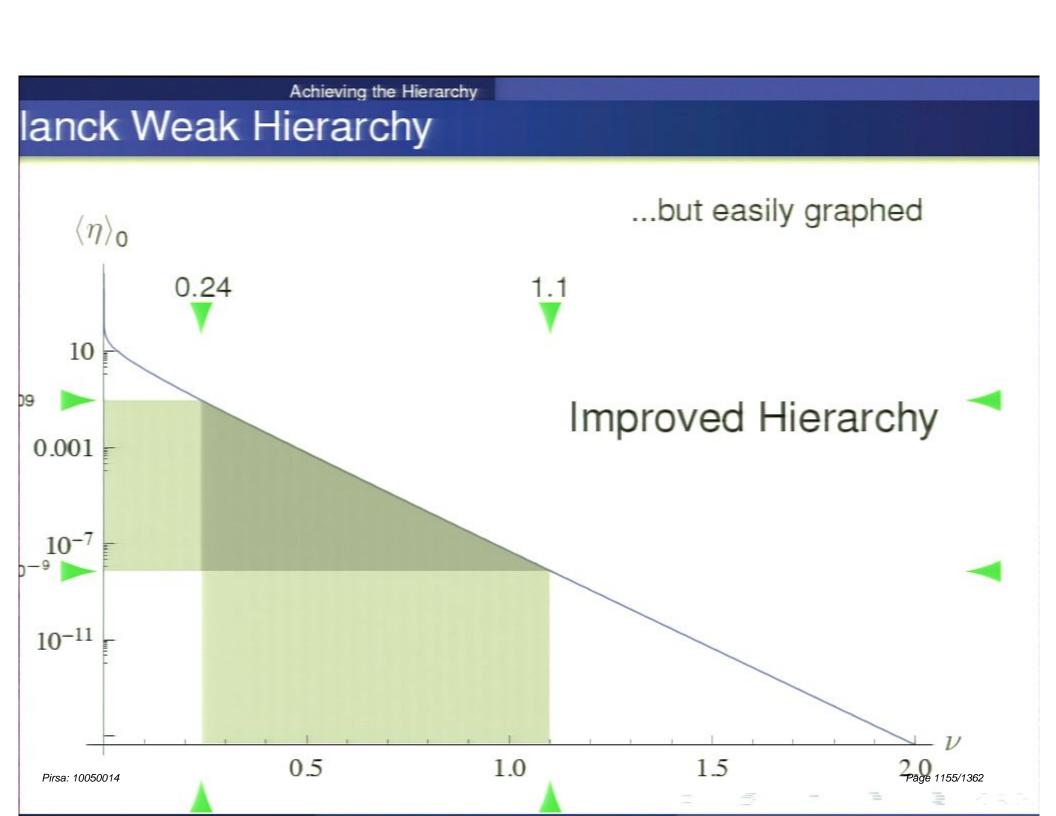
% change in $\langle \eta \rangle_0$ for 1% change in weak scale

 $\sim 1/4$ 0.1% (fairly robust)

 $\leq \nu \leq$ 3 1% (robust)

>> 1 very sensitive to variation

course, ν has other consequences...



The value of the field at the UV brane is

$$\eta_{0} = \pm \sqrt{3} \left(\frac{\nu + 1}{\nu} \right) \left[\sqrt{\frac{2}{3} \frac{\nu}{\nu + 1}} \left(\frac{\mu}{k} \right)^{\nu} + \left(\frac{2}{3} \frac{\nu}{\nu + 1} \left(\frac{\mu}{k} \right)^{\nu} \right)^{2} + \sinh^{-1} \sqrt{\frac{2}{3} \frac{\nu}{\nu + 1}} \left(\frac{\mu}{k} \right)^{\nu} \right]$$

Not easily inverted...

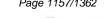
Pirsa: 10050014 Page:

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Pirsa: 10050014 Page 1161/136

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Pirsa: 10050014 Page 1162/1362

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Pirsa: 10050014 Page 1163/136

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Pirsa: 10050014 Page 1167/136

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Pirsa: 10050014 Page 1170/13

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Pirsa: 10050014 Page 1174/136

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Not easily inverted...

Pirsa: 10050014 Page 1175/1

The value of the field at the UV brane is

$$\eta_0 = \pm \sqrt{3} \left(\frac{\nu+1}{\nu} \right) \left[\sqrt{\frac{2}{3} \frac{\nu}{\nu+1}} \left(\frac{\mu}{k} \right)^{\nu} + \left(\frac{2}{3} \frac{\nu}{\nu+1} \left(\frac{\mu}{k} \right)^{\nu} \right)^2 \right.$$

$$\left. + \sinh^{-1} \sqrt{\frac{2}{3} \frac{\nu}{\nu+1}} \left(\frac{\mu}{k} \right)^{\nu} \right]$$

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Pirsa: 10050014 Pag

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Pirsa: 10050014 Page 1178/13

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Not easily inverted...

Pirsa: 10050014 Page 11

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Not easily inverted...

Pirsa: 10050014 Page 1187/1

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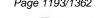
Not easily inverted...

Pirsa: 10050014 Page 1192/136

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Pirsa: 10050014 Page 1197/136

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Pirsa: 10050014 Page 1199/136

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Pirsa: 10050014 Page 1202/136

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Pirsa: 10050014 Page 1203/136

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Not easily inverted...

Pirsa: 10050014 Page 1208/136

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Not easily inverted...

Pirsa: 10050014 Page 1209/136

The value of the field at the UV brane is

$$\eta_{0} = \pm \sqrt{3} \left(\frac{\nu + 1}{\nu} \right) \left[\sqrt{\frac{2}{3} \frac{\nu}{\nu + 1} \left(\frac{\mu}{k} \right)^{\nu} + \left(\frac{2}{3} \frac{\nu}{\nu + 1} \left(\frac{\mu}{k} \right)^{\nu} \right)^{2}} + \sinh^{-1} \sqrt{\frac{2}{3} \frac{\nu}{\nu + 1} \left(\frac{\mu}{k} \right)^{\nu}} \right]$$

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Not easily inverted...

Pirsa: 10050014 Page 1212/136

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Not easily inverted...

Pirsa: 10050014 Page 1213/13

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Not easily inverted...

Pirsa: 10050014 Page 1215/136

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Not easily inverted...

Pirsa: 10050014 Page 12

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Not easily inverted...

Pirsa: 10050014 Page 1217/136

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Not easily inverted...

lanck Weak Hierarchy Robustness

an also ask how sensitive $\langle \eta \rangle_0$ is to μ/k (and vice-versa).

% change in $\langle \eta \rangle_0$ for 1% change in weak scale

 $\sim 1/4$ 0.1% (fairly robust)

 $\leq \nu \leq$ 3 1% (robust)

>> 1 very sensitive to variation

course, ν has other consequences...

calar's Potential

ok at potential

$$V(\eta) = -12k^2 - k^2\nu\left(1 - \frac{\nu}{8}\right)\eta^2 + \cdots$$

ves η 's mass as

$$m_{\eta}^2 = -2k^2\nu \left(1 - \frac{\nu}{8}\right)$$

S/CFT correspondence says operator dimension is

$$\Delta = 2 + \sqrt{4 + \frac{m_{\eta}^2}{k^2}} = 2 + \frac{1}{2}|4 - \nu|$$

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perator Dimension

e breakdown is

Hierarchy by Hand
$$\nu > 1$$

$$\nu > 1$$

$$\Delta > \frac{5}{2}$$

Improved Hierarchy
$$\nu \sim 1$$
 $\Delta \sim \frac{5}{2}$

$$\nu \sim 1$$

$$\Delta \sim \frac{5}{2}$$

Natural Hierarchy
$$0 < \nu < 1$$
 $2 < \Delta < \frac{5}{2}$

$$0 < \nu < 1$$

$$2 < \Delta < \frac{5}{2}$$

perator Dimension

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Hierarchy by Hand
$$\nu > 1$$

$$\Delta > \frac{5}{2}$$

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$$\nu \sim 1$$
 $\Delta \sim \frac{5}{2}$

Natural Hierarchy
$$0 < \nu < 1$$
 $2 < \Delta < \frac{5}{2}$

Hierarchy by Hand
$$\nu > 1$$

$$\nu > 1$$

$$\Delta > \frac{5}{2}$$

Improved Hierarchy
$$\nu \sim 1$$
 $\Delta \sim \frac{5}{2}$

$$\nu \sim 1$$

$$\Delta\sim {5\over 2}$$

Natural Hierarchy
$$0 < \nu < 1$$
 $2 < \Delta < \frac{5}{2}$

$$0 < \nu < 1$$

$$2<\Delta<\frac{5}{2}$$

Hierarchy by Hand
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Fluctuations

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u}+h_{\mu
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Aectol Wones

andy zero moder higher modes eaten by massive tensor

Scalar Modés

gravi-scalar: E

scalar tower of a

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two massless modes

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- Massive modes Schrödinger Potential
 - Behavior similar to massive tensors

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 $z \to \infty \Rightarrow V_{SE} \to \infty$

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 $Z \to \infty \Rightarrow V_{SE} \to \mu^2$

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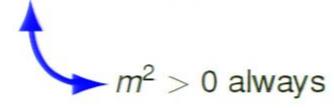
- Massive modes Schrödinger Potential
 - Behavior similar to massive tensors

$$\nu > 1$$
 $z \to \infty \Rightarrow V_{SE} \to \infty$

$$\nu = 1$$
 $Z \to \infty \Rightarrow V_{SE} \to \mu^2$

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• For ν < 1, $V_{\rm SE}$ > 0 for all z



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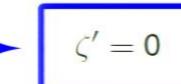




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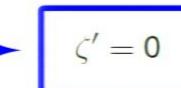


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Pirsa: 10050014 Page 1303/1362

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Pirsa: 10050014 Page 1304/1362

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calar Modes - No Massless - Physical Reason

Can better understand lack of massless modes

Pirsa: 10050014 Page 1348/1362

$$V = -12k^{2} + \frac{1}{2}m_{\phi}^{2}\phi^{2} - \frac{\lambda}{12}\phi^{4}$$

$$\lambda_{UV} = 12k^{2} - u\phi_{UV} - 2u\phi_{UV}(\phi - \phi_{UV}) + \frac{1}{2}\mu_{UV}(\phi - \phi_{UV})^{2}$$

$$m_{\phi}^{2} = 4ku + u^{2}$$

$$\lambda = u^{2}$$

$$A(y) = ky + \frac{1}{24}\left(\langle\phi\rangle^{2} - \langle\phi\rangle_{UV}^{2}\right)$$

$$\langle\phi\rangle = \phi_{UV}e^{-uy}$$

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- Found natural hierarchy for $\nu < 1$
- ν < 1 corresponds to fractional-dimension operators in dual theory
- ν < 1 also implies a continuum of modes in the 5D theory
- Thus, natural hierarchy implies unparticles
- Furthermore, can get phenomenologically viable Standard Model Fields

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