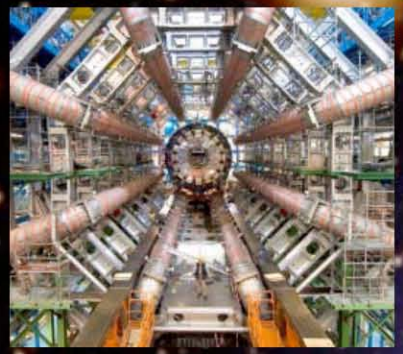
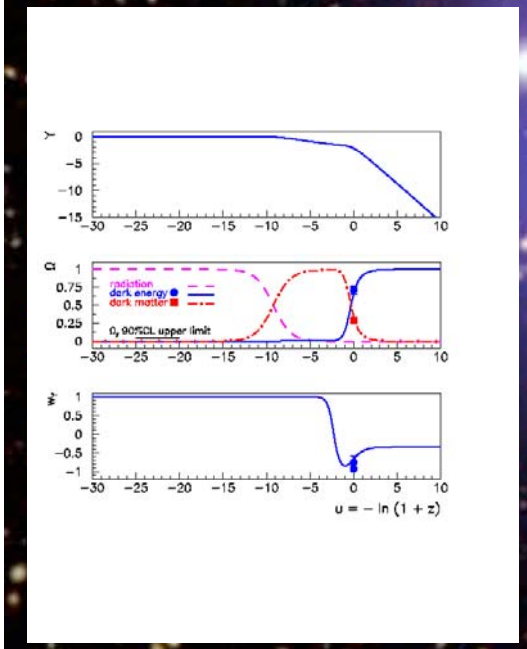
The Hunt for Dark Matter

A Symposium on Collider, Direct and Indirect Searches

Fermilab May 10-12, 2007





Hosted by the Fermilab Center for Particle-Astrophysics

Stringy Echoes from the Dark Side

Luis Anchordoqui

University of Wisconsin - Milwaukee

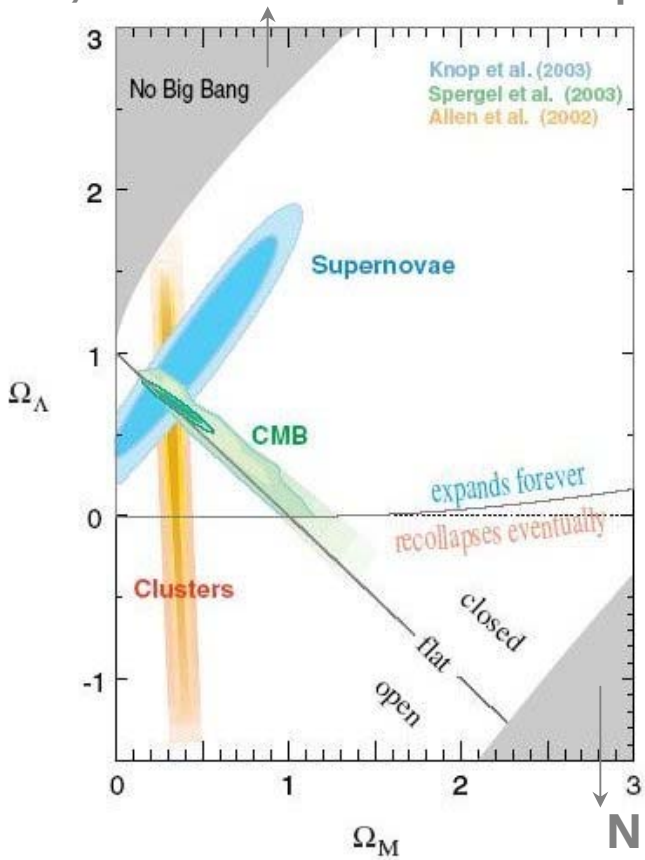
Work done with Haim Goldberg, Satoshi Nawata, and Charles Nuñez

arXiv:0704.0928

Living in the dark

Universe has a turning point in its past

Carroll, Press, and Turner, Ann. Rev. Astron. Astrophys. 30, 499 (1992)



Nucleocosmochronology

Universe younger than long-lived radioactive isotopes for H_0 > 50 km/s Mpc

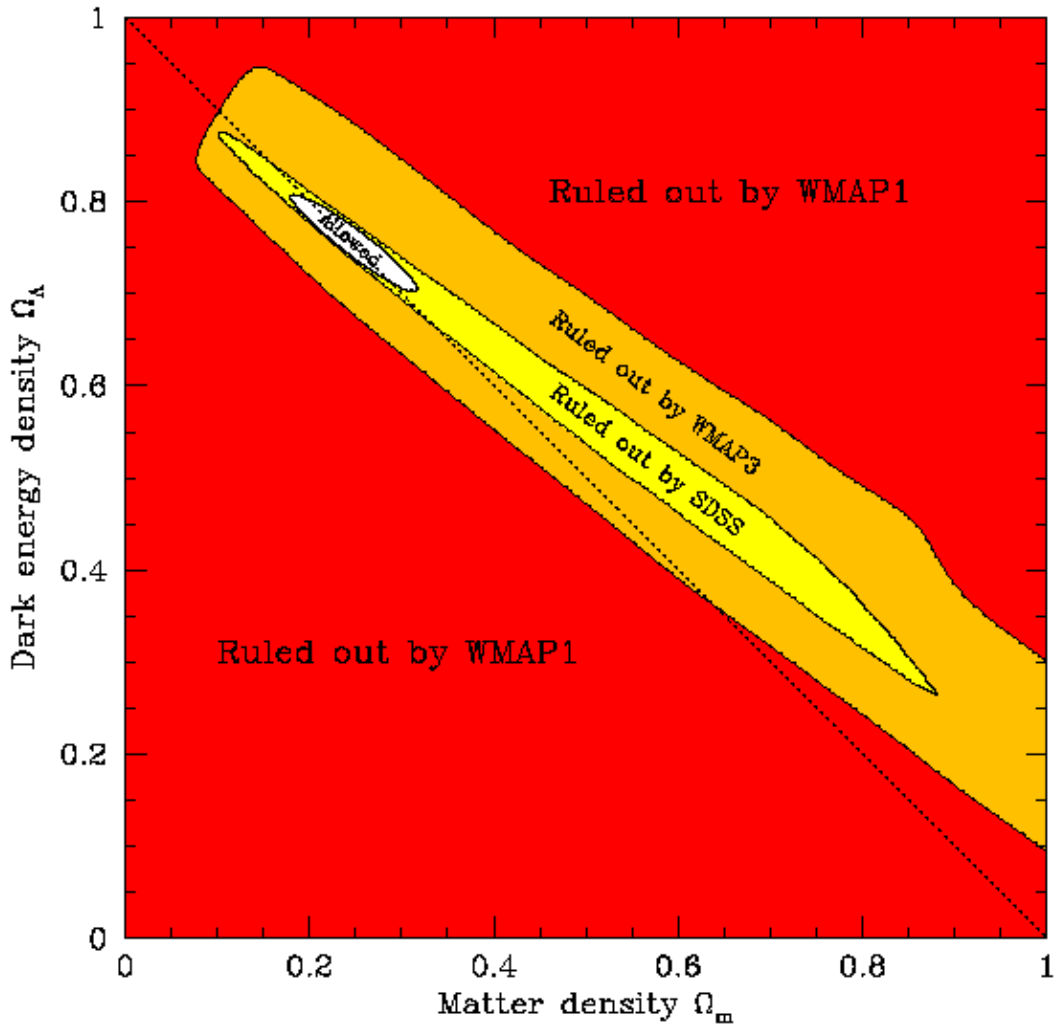
Meyer and Schramm, Astrophys. J. 311, 406 (1986)

Supernova Cosmology Project Collaboration, Astrophys. J. 598, 102 (2003)

WMAP Collaboration, Astrophys. J. Suppl. 148, 175 (2003)

Allen, Schmidt, and Fabian, Mon. Not. Roy. Astron. Soc. 334, L11 (2002)

Recent Observations



Tegmark et al. Phys. Rev. D74 123507 (2006)

de-Sitter in String/M-theory – a tough business

- **No-go theorem of Maldacena and Nuñez:**

Int. J. Mod. Phys. A16 822 (2001)

In a D-dimensional theory of supergravity with

- **all D-4 extra (internal) dimensions compact**
- **the action linear in R and**
- **no local sources (a la Randall-Sundrum)**

Phys. Rev. Lett. 83, 3370 (1999)

You cannot have a de-Sitter vacuum

Salam-Sezgin to the rescue

- A model of 6D supergravity

  with a 2D compact space containing a monopole

  Salam and Sezgin, Phys. Lett. B147, 47 (1984)

- When ¨lifted¨ to 10D the remaining 4D are non-compact

  Cvetic, Gibbons and Pope, Nucl. Phys. B677, 164 (2004)

- This circumvents no-go theorem

- Static solution $\Downarrow$

  bosonic sector has only supersymmetric ground state

  (non de-Sitter)

  Time-dependent moduli change this

  what are cosmological consequences?

The model

The action...

$$S = \frac{1}{2G_6}\int d^6x\sqrt{g_6}\Big[R \;-\; (\partial_M\phi)^2 - \frac{\xi}{G_6}e^{\phi}$$

$$-\frac{G_6}{2}e^{-\phi}F_{MN}^2 \;-\; \frac{G_6}{6}e^{-2\phi}G_{MNP}^2\Big]$$

The metric...

$$ds_6^2 \;=\; ds_4(t,\vec{x})^2 + e^{2f(t,\vec{x})}d\sigma^2$$

$$d\sigma^2 \;=\; \begin{cases} r_c^2\,(d\vartheta^2 + \sin^2\vartheta d\varphi^2) & \text{for } S^2 \\ r_c^2\,(d\vartheta^2 + \sinh^2\vartheta d\varphi^2) & \text{for } \Sigma_2 \end{cases}$$

the monopole gauge field

$$A_\varphi = \begin{cases} b\cos\vartheta & (S^2) \\ b\cosh\vartheta & (\Sigma_2) \end{cases}$$

the field strength energy density…

$$F_{MN}^2 = 2b^2 e^{-4f}/r_c^4$$

the Ricci scalar…

$$R[M] = R[N_1] + e^{-2f} R[N_2] - 4\Box f - 6(\partial_\mu f)^2$$

$$R[N_2] = \begin{cases} +2/r_c^2 & (S^2) \\ -2/r_c^2 & (\Sigma_2) \end{cases}$$

The reduction

the 4D/6D connection...

$$\frac{1}{G_4} \equiv \frac{M_{\rm Pl}^2}{2} = \frac{1}{2\,G_6}\int d^2\sigma\sqrt{g_\sigma} = \frac{2\pi r_c^2}{G_6}$$

some rescaling to go to Einstein frame

some redefinition...

$$X \equiv (\phi + 2f)/\sqrt{G_4} \qquad\qquad Y \equiv (\phi - 2f)/\sqrt{G_4}$$

and some algebra...

$$L = \sqrt{g}\left[\frac{R}{G_4} - \frac{1}{2}(\partial X)^2 - \frac{1}{2}(\partial Y)^2 - V(X,Y)\right]$$

$$V(X,Y) = \frac{e^{\sqrt{G_4}Y}}{G_4}\left[\frac{G_6 b^2}{r_c^4}e^{-2\sqrt{G_4}X} - R_2 e^{-\sqrt{G_4}X} + \frac{\xi}{G_6}\right]$$

With a metric

$$ds^2 = -dt^2 + e^{2h(t)}d\vec{x}^{\,2}$$

only $X(t)$ and $Y(t)$ find

Working equations

$$\ddot{X} + 3H\dot{X} = -\partial_X V$$

$$\ddot{Y} + 3H\dot{Y} = -\partial_Y V$$

$$H^2 = (G_4/6)\left[(\dot{X}^2 + \dot{Y}^2)/2 + V(X,Y)\right]$$

V **has a global min** $\Leftrightarrow R_2 > 0$ **(spherical compactification)**

Expand

$$\overline{M_X} \equiv \frac{1}{\sqrt{\pi}\ br_c}$$

$$V(X,Y) = \frac{e^{\sqrt{G_4}Y}}{G_4}\left[\mathcal{K} + \frac{\overline{M_X}^2}{2}(X - X_0)^2 + \ldots\Big)\right]$$

$$\mathcal{K} \equiv \frac{M_{\rm Pl}^2}{4\pi r_c^2 b^2}\left(b^2\xi - 1\right)$$

SUSY, de-Sitter, and VAMPs

- Salam-Sezgin show that SUSY requires $b^2\xi = 1$ corresponding to winding number ± 1

- X particles have Y-dependent mass (VAMP)

Comelli, Pietroni, and Riotto, Phys. Lett. B571, 115 (2003)

$$M_X(Y) = \frac{e^{\sqrt{G_4}\,Y/2}}{\sqrt{G_4}}\,\overline{M_X}$$

- classical oscillations ~ axions CDM

Preskill, Wise, and Wilczek, Phys. Lett. B120, 127 (1983)

- a non-zero dS (vacuum) potential

$$V_Y = \frac{e^{\sqrt{G_4}\,Y}}{G_4}\,\mathcal{K}$$

if $b^2\xi > 1$

The energy components

- For the X contribution

$$\rho_X(Y,u) = M_X(Y)\; n_X(u) = C\; e^{\sqrt{G_4}Y/2}\; e^{-3u}$$

$$u \equiv -\ln(1+z)$$

- Additional contributions

$$\rho_{\rm mat} = Be^{-3u} \qquad \rho_{\rm rad} = 10^{-4}Be^{-4u}$$

from SM fields confined to *4D space*

- Define

$$V_{\rm eff}(Y,u) \equiv V_Y + \rho_X = A\, e^{\sqrt{G_4}Y} + C\, e^{\sqrt{G_4}Y/2}\, e^{-3u}$$

Cosmology

The working equations...

$$\ddot{Y} + 3\,H\,\dot{Y} = -\frac{\partial V_{\rm eff}}{\partial Y}$$

$$H^2 = \frac{1}{3}\left[\frac{1}{2}\dot{Y}^2 + V_{\rm eff} + \rho_{\rm rad} + \rho_{\rm mat}\right]$$

In terms of u

$$\frac{Y''}{1 - Y'^2/6} + 3\,Y' + \frac{\partial_u \rho \;\; Y'/2 \;\; + \; 3 \;\partial_Y V_{\rm eff}}{\rho} = 0$$

Solution depend only on ratio $A : B : C$

Boundary Conditions

- In radiation era

  equation has solution $Y =$ constant

  so can pick $Y(-30) = 0$ and adjust A

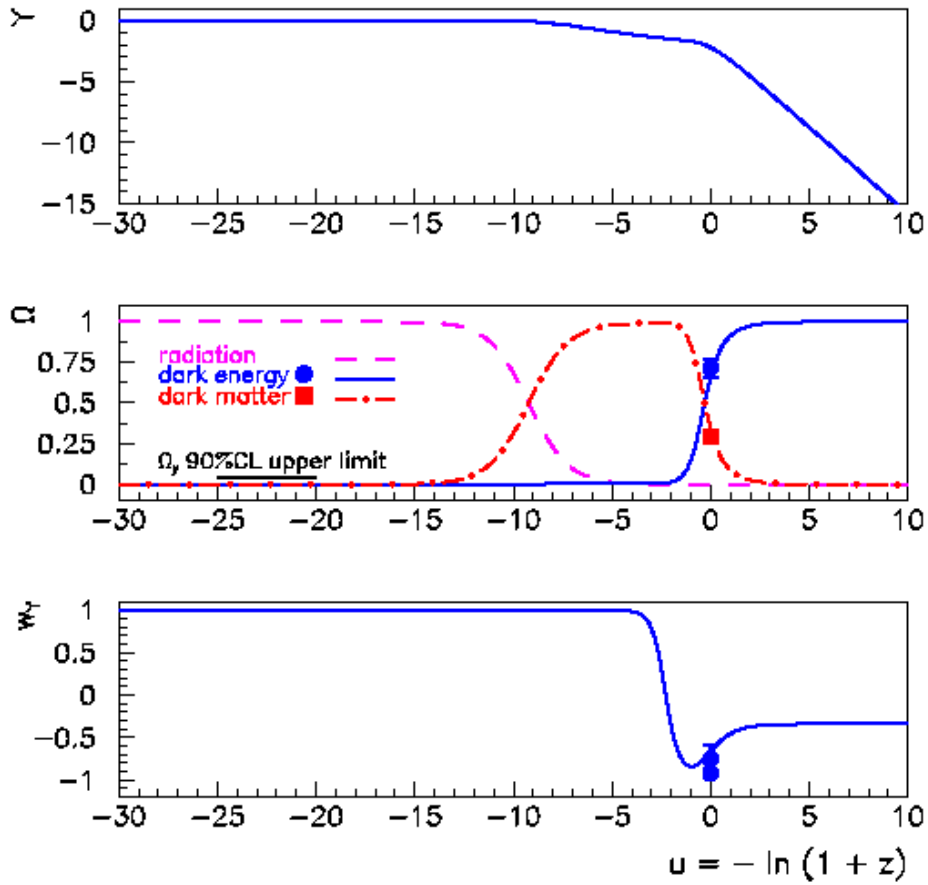
- Equipartition of KE and PE in distant past

$$\Downarrow$$

$$Y'(-30) = 0.08$$

- Arbitrarily fix B then adjust A and C

Out of the darkness



●**WMAP Collaboration, astro-ph/0603449**

■**WMAP Collaboration, astro-ph/0603449**

- Bean, Hansen, and Melchiorri, Nucl. Phys. Proc. Suppl. 110, 167 (2002)

Fine Tunes

• VAMP component of DM
cannot be above 7% without serious harm to fit

• We have

$$\frac{V_Y(\text{now})}{\rho_{\text{mat}}(\text{now})} = \frac{A}{B}\, e^{\sqrt{2}Y(\text{now})} \simeq 36\, e^{\sqrt{2}Y(\text{now})}$$

Also

$$\rho_{\text{mat}}(\text{now}) \simeq 0.3\rho_c(\text{now}) \simeq 10^{-120}\, M_{\text{Pl}}^4$$

• Matching equation for V_Y with this result → find

$$\boxed{b^2\xi - 1 \simeq 10^{-117}\, (r_c\, b)^2}$$

Conclusions

- 6D Salam-Sezgin w/ U(1) 2D monopole ⇓

  has Minkowski$_4$ x S^2 static solution

- Lifted to String/M Theory ⇓

  non-compact internal dimensions ⇓

  Possible dS phase w/ tiny violations of SUSY

- 6D dilaton and 2D moduli ⇓

  (1) Quintessence

  (2) a VAMP CDM candidate

- Variations in fine structure constant are negligible

- Moduli forces are short range