Cosmological Acceleration from a gas of strings

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Acceleration from a gas of strings

Observations indicate that the Universe's expansion rate has accelerated in the later stages of its evolution.

Theoretical attempts to understand gravity at the fundamental (quantum) level are usually formulated in a spacetime which has more dimensions than the observed 3+1.

String Gas Cosmology (SGC) explains the dimensionality of the spacetime dynamically, and is compatible with a phase of late-time acceleration.

Outline

Introduction: evolving from 10D to 4D

Late-time FRW phase

Comparison with SNIa data

FF, Tuomas Multamäki and Syksy Räsänen, arXiv:0812.4182
FF and Syksy Räsänen, JHEP 0711:003,2007

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Why do we live in 3+1 D?

- Attempts to understand the different interactions in nature at the fundamental level, frequently predict the existence of extra dimensions. Yet, our universe seems to be 4D.
- In SGC, unlike in most applications of string theory, all spatial dimensions are treated on an equal footing: they are all small, and filled with a hot gas of branes of all allowed dimensionalities. Dynamical processes in the early universe will allow only three dimensions to expand to macroscopic size, while the extra dimensions are stabilized at the string size by a gas of strings.
- SGC explains not only why some dimensions are hidden, but also why the number of visible dimensions is three.

Kripfganz & Perlt 88, Brandenberger & Vafa 89, Tseytlin & Vafa 92

Early evolution

The EOM of a closed string in the background of its massless models can be derived (up to $\mathcal{O}(\alpha')$) from the effective action of supergravity:

$$S = \frac{1}{2\kappa_D^2} \int d^D x \sqrt{-G} e^{-2\phi} \left(R + c + 4 (\nabla\phi)^2 - \frac{1}{12} H^2 \right).$$

There is a new symmetry,

$$a_i \to 1/a_i \qquad \varphi \to \varphi,$$

with interesting consequences for cosmology. A rolling dilaton can be problematic, and we assume that it has been stabilized at late-times.

Cosmological solutions

Simplest generalization separately isotropic in the visible and extra dimensions:

$$\mathrm{d}s^2 = -\mathrm{d}t^2 + a(t)^2 \sum_{i=1}^{3} \mathrm{d}x^i \mathrm{d}x^i + b(t)^2 \sum_{j=1}^{6} \mathrm{d}x^j \mathrm{d}x^j .$$

For consistency,

$$T^{\mu}_{\nu} = \mathrm{diag}(-\rho(t), p(t), p(t), p(t), P(t), P(t), P(t), P(t), P(t), P(t)) .$$

Adding string matter to the EM tensor

It seems natural to include the massless string states in the action:

$$l_s^2 E^2 = a^{-2} \sum_{i=1}^{3} N_i^2 + \sum_{j=1}^{6} \left(b^{-1} N_j + b W_j \right)^2 + 4(N-1) \, .$$

Then, a gas of strings contributes $\rho = \sum_{\text{states}} n_{\text{state}}$. In the simplest case of bosonic string gases:

$$p_w = -\frac{1}{d} \rho_w , \qquad p_m = \frac{1}{d} \rho_m .$$

Momentum modes scale as radiation, while winding modes contribute negative pressure.

Obtaining 3 large dimensions

p-dimensional objects can intersect in at most 2 p + 1 dimensions.

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Since the winding strings should be around today, one usually assumes that the spatial dimentions are toroidal. Easson 01, Easther, Greene & Jackson 02.

The same kind of dynamical process has been used in braneworld scenarios. Durrer, Kunz & Sakellariadou 05, Karch & Randall 05

The string gas model

Since we assume a stabilized dilaton, the EOM reduces to the Einstein eq:

$$\begin{aligned}
\kappa^2\rho &= 3H_a^2 + 18H_aH_b + 15H_b^2 \\
\dot{H}_a + H_a^2 &= -\frac{1}{6}\kappa^2(\rho+3p) - \frac{3}{8}\kappa^2(\rho \\
&\quad -3p+2P) + 6H_aH_b + 10H_b^2 \\
\kappa^2(\rho-3p+2P) &= 8\dot{H}_b + 24H_aH_b + 48H_b^2 \,,
\end{aligned}$$

The string gas model

With the composition,

$$\rho = \rho_{m,in} M^{-3} a^{-3} b^{-6} \left(1 + r a^{-1} + r f_s \sqrt{a^{-2} + b^{-2} + b^2 - 2}\right).$$

The evolution depends on only two dimensionless combinations:
$r \equiv M^{-1} \frac{\rho_{\gamma,in}}{\rho_{m,in}}$ and $f_s \equiv \frac{\rho_{s,in}}{\rho_{\gamma,in}}$.

Dust and Strings

In the radiation era $\rho - 3p + 2P = 0$, the extra dimensions stay at b = 1.

When dust becomes important, the driving term becomes positive and b grows. From the 4D point of view it looks like a t-dependent Newton's constant:

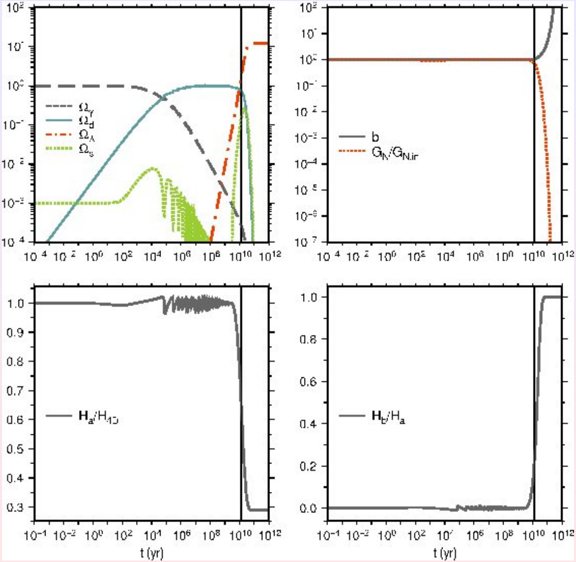
$$8\pi G_N = \kappa^2 l_s^6 b^{-6}.$$

From observations of ^{4}He and D abundance

$$G_{N0}/G_{N,BBN} = 0.98^{+0.25}_{-0.18} \Rightarrow b_0 = 1.00^{+0.04}_{-0.03},$$

gives a bound on the *final* value of b.

A *Concordance* composition



An oscillating acceleration

- The strings which stabilize the extra dimensions during the radiation dominated era can counter the destabilizing push of 4D pressureless matter (baryons or dark matter).
- The competition between the push of dust and the pull of strings cannot make the extra dimensions static, but it can lead to oscillations around the self-dual radius with decreasing amplitude, so that the extra dimensions can be effectively stabilized.
- Vacuum energy will lead to decompactification, and the strings cannot help here. However, we can obtain acceleration without any extra dark energy component: *the oscillations induced by dust and strings can involve transitions between deceleration and acceleration, even when the energy density of the universe is dominated by matter*.

The luminosity distance

The usual FRW relation between distance and expansion rate,

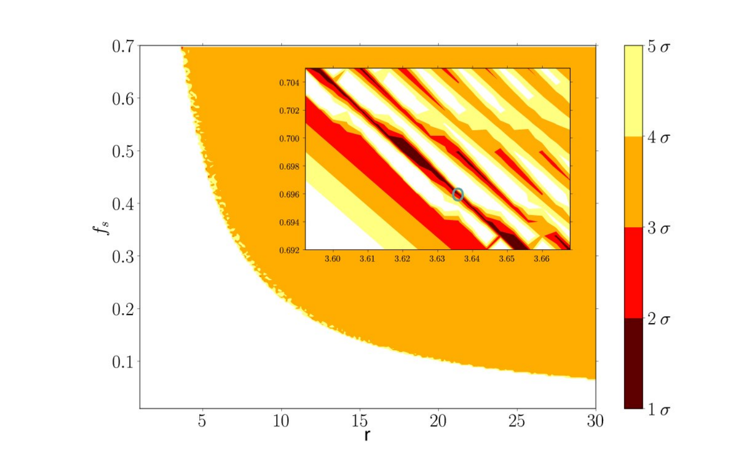
$$D_L = (1+z)\int_0^z \frac{dz'}{H(z')},$$

does not hold. Räsänen 08

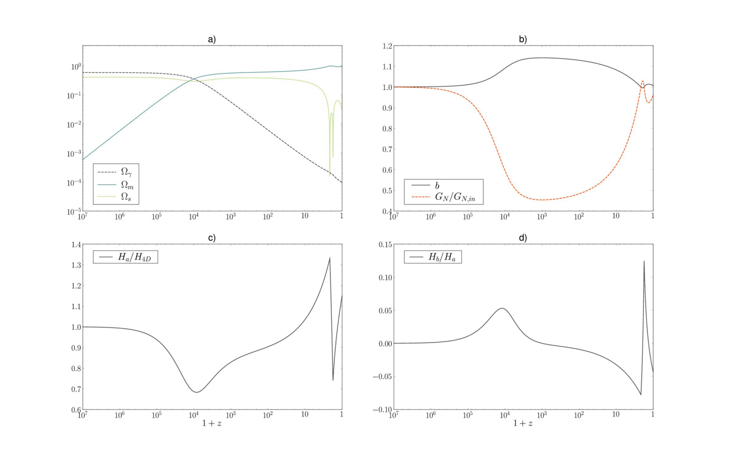
Instead, with $D = D_L/(1+z)^2$, we need to solve:

$$H_a\partial_z\left((1+z)^2 H_a\partial_z D\right) = \left(\partial_t H_a + 3\partial_t H_b + 3H_b^2 - 3H_aH_b\right) D$$

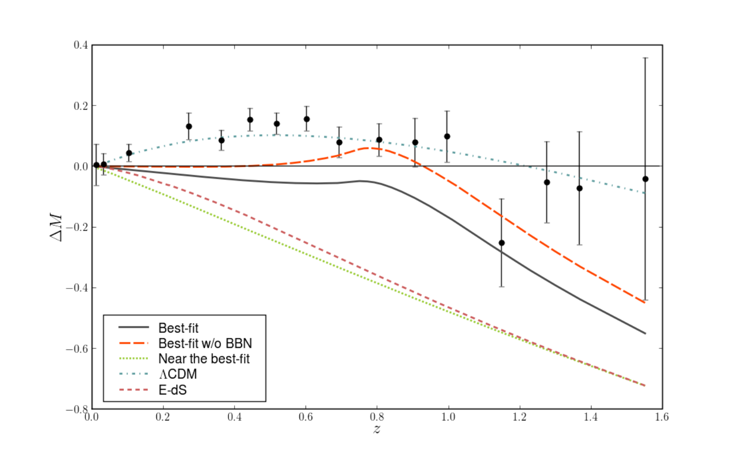
Parameter scan



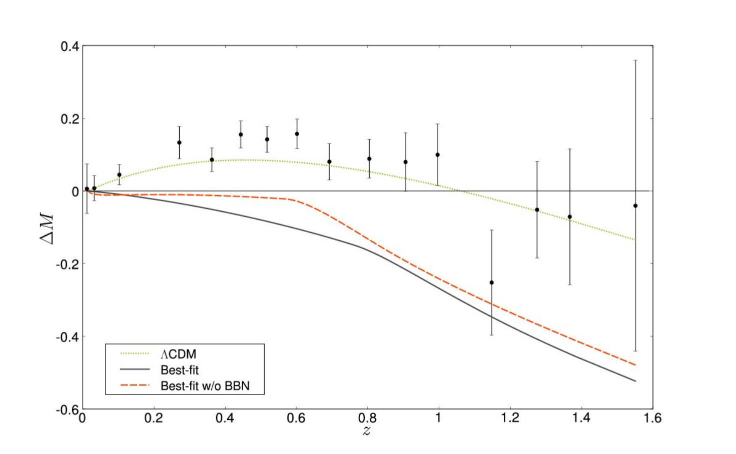
Cosmological evolution



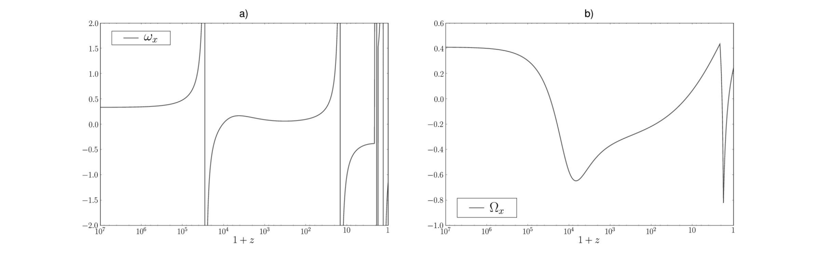
Luminosity distance I



Luminosity distance II



Equation of state



Summary

- In the SGC framework (anti-)winding modes survive to allow only the growth of 3 spatial dimensions.
- A cosmological constant would destabilize the extra 6D. However, Λ is not necessary to explain the recent period of accelerated expansion: it could be due to oscillations in these extra dimensions.
- Contrasting the predicted background evolution to SN Ia observations suggests that this non-standard late-time evolution is not favored wrt the ΛCDM model, although surprisingly the fit is not much worse.
- BBN predictions are upset by the addition of relativistic dof, but with slight modifications this scenario could be brought into agreement with the observed light element abundances.