The Stryngbohtyk Model of the Universe: A Solution to the Problem of the Cosmological Constant

Jordi Miralda-Escudé

Institut de Ciències de l’Espai (IEEC-CSIC)/ICREA, Barcelona

miralda@ieec.uab.es

ABSTRACT

Astronomical observations have shown that the expansion of the universe is at present accelerating, in a way consistent with the presence of a positive cosmological constant. This is a major puzzle, because we do not understand: why the cosmological constant is so small; why, being so small, it is not exactly zero; and why it has precisely the value it must have to make the expansion start accelerating just at the epoch when we are observing the universe. We present a new model of cosmology, which we call the stryngbohtyk model, that solves all these problems and predicts exactly the value that the cosmological constant must have. The predicted value agrees with the observed one within the measurement error. We show that in the stryngbohtyk model, the fact the cosmological constant starts being important at the present epoch is not a coincidence at all, but a necessity implied by our origin in a planet orbiting a star that formed when the age of the universe was of the same order as the lifetime of the star.

Subject headings: cosmology: theory – shape of the universe – anthropic principle is rubbish – strings, branes and funnels

1. Introduction

We have learned over the last decade that the expansion history of our universe is described by the Friedmann equation derived from the General Theory of Relativity with the addition of a cosmological constant, which has just the value that makes the expansion start accelerating around the present epoch. Evidence for this strange result has come from the observations of the detailed shape of the power spectrum of fluctuations in the Cosmic Microwave Background (Spergel et al. 2006 and references therein), Type Ia supernovae (Riess et al. 2006 and references therein), and other confirming evidence such as the values
of the Hubble constant and the age of the oldest known stars, and the evolution of galaxy clusters. If the accelerated expansion is interpreted as the result of a component with negative pressure \( p = w \rho c^2 \), present observations show that \( w \) is consistent with a constant value of \(-1\), corresponding to the simple case of a cosmological constant.

The cosmological constant has an interesting history. Einstein first added it to the equations of General Relativity in order to obtain a static, closed universe, where matter’s attraction and the cosmological constant repulsion exactly balance each other. After the expansion of the universe was discovered by Hubble in 1929, the cosmological constant was discarded and astronomers took to the task of measuring the only two parameters that were thought to be left to measure, the Hubble constant and the matter density (although the Steady State model of the universe was proposed as an alternative until it was observationally ruled out). After seven decades of controversy, astronomers finally managed to measure the evolution of the expansion rate of the universe around the turn of the century, and they had to agree that there is, after all, evidence for the kind of accelerated expansion that is produced by the cosmological constant, in a flat universe. Now, just like it happened after Hubble’s discovery of the expansion, all the astronomers are getting excited about measuring more details of this acceleration and learning the fate of the universe.

It is curious that, despite the absence of any really new theoretical developments to understand the reason for the accelerated expansion, and despite the perfect agreement of the observations with the most simple possibility of a cosmological constant, countless papers are being published on the possibilities to produce accelerated expansion: all types of modifications of gravity, as well as hypothetical components with negative pressure that have been named “dark energy”. The exhilaration has reached such an extreme that cosmologists are heard these days talking about “dark energy” as if this were a real, already detected substance.

As a note, the name dark energy for a component driving the acceleration is particularly bad among all the bad terminology that astronomers have made up, because Einstein discovered that

\[ E = mc^2, \]  

(this equation is written here in case anybody had forgotten it), so everything in the universe is energy (and the name “dark stuff” would be no worse than dark energy). Moreover, dark means something that absorbs the light, whereas something that lets all the light go through without interaction should be called transparent, or invisible (which means detectable only through gravity, because Einstein found that nothing can be invisible to gravity). Perhaps a better name would be invisible tension: the distinguishing property of a component of the universe accounting for the acceleration would have to be, after all, its negative pressure.
The detection of the present acceleration of the expansion poses a very deep puzzle for cosmology and for all physics. What this observation is telling us is that the cosmological constant has a value that is 123 orders of magnitude smaller than its only natural magnitude one can think of, the Planck density. So, the terrible questions we face are: Why is the cosmological constant so small compared to this natural value? (this is the question we had before, on which we have made no progress); why, being so small, is the value not exactly zero? (so, it is not enough to have some symmetry that makes the cosmological constant be zero, but some small correction is needed); and why, being not exactly zero, it just happens to have exactly the value that makes its density similar to the average matter density, at the time when a biological species that may be more or less intelligent and has appeared in some random planet starts to wonder about the universe? (Well, at least some of the individuals in the species do; most care only about money, sex, football, and management of power). In fact, the epoch when the cosmological constant is exactly half of the total energy density is at redshift $\sim 0.3$, very close to the present. The problem is so hard to deal with that some cosmologists, losing all shame, have even appealed to anthropic principles.

This paper presents a new model of cosmology, the stryngbohtyk\footnote{The etymology of the word stryngbohtyk comes from the Catalan language, from the word “estrambòtic”, which means something that is out of the ordinary in an extravagant and laughable way.} model of the universe. It solves all the problems associated with this detection of the accelerating expansion: it predicts exactly the value the cosmological constant must have, and, you will be amazed to find out, the value agrees with the measured one within the error. Moreover, it will be shown that the similarity of the predicted value with the present matter density is not a coincidence at all, but is a necessity: whenever an intelligent species arises in a planet at a time when the age of the universe is of the same order as the lifetime of its host star, the epoch when the acceleration starts must be roughly of the same order as the epoch at which the universe is observed.

2. The origin and shape of the universe in the stryngbohtyk model

All the present cosmological data is explained by the structure formation model of Cold Dark Matter, which postulates that the dark matter is made of collisionless particles or objects that have a negligible initial velocity dispersion, and that there are Gaussian, adiabatic primordial perturbations with a nearly scale-invariant power-law power spectrum. This was initially postulated for reasons of simplicity. The amazing thing is how well this simple model fits the very detailed measurements of the CMB by the WMAP mission, as
well as various other astronomical observations of large-scale structure, once the cosmological constant is included.

In this context, present cosmology has come to be dominated by the concept of inflation, which essentially proposes the very naive and generic idea that the primordial perturbations were causally generated in the early universe and then inflated out of the horizon by an accelerated expansion similar to the one that is starting at present (although with a much higher Hubble rate). Then, this idea is used to attribute all the success of the Cold Dark Matter model matching the observations to the inflationary ideology, hence greatly inflating inflation’s merits. Moreover, inflation has the advantage of making a lot of predictions, which can be changed whenever they are not matched by observation. In this way, the concept of inflation becomes an eternally self-reproducing one in the minds of cosmologists.

Despite inflation’s great success, it is always worth considering alternatives, like the cyclic model (see Steinhardt & Turok 2005 and references therein). The new model we present in this paper, called the stryngbohtyk model, takes a further step in sophistication. Like in the cyclic model, the universe in the stryngbohtyk model is a brane that is contained in some higher dimensional space that is called the bulk, and the particles that we see are strings that are confined to the brane, and can only interact with other strings in the brane. However, whereas the cyclic model has two flat branes separated by a short distance across the bulk, which hit each other at the end of each cycle starting a new Big Bang (after a period of accelerated expansion of the branes in which the entropy of the old cycle gets diluted), the stryngbohtyk model has only one brane which is closed. After the brane undergoes a period of exponential expansion, then instead of having two plane-parallel, infinite branes which hit each other nearly simultaneously everywhere and bounce back, the closed brane of the stryngbohtyk model hits itself at some singular point, or string. When the brane hits itself, it can rupture and get reconnected, and develop a topological hole. After the collision, the universe bounces back and starts exponential expansion again, generating primordial perturbations until reheating occurs, making everything just like inflation (whereas in the original cyclic model the Big Bang phase starts after the brane collision, and the perturbations are created before the collision). This is good news, for as inflationary cosmologists say, any model explaining the flatness and horizon and the rest of you-know-which problems is like inflation, or else it must be wrong.

For example, a brane that is initially like a two-dimensional sphere may contract, becoming some sort of pancake and finally hitting itself at one point. At the collision, the brane gets ripped up and reconnected with a topological hole, undergoing a transition that converts it into a doughnut. Then, any strings that happened to be lying around the point of rupture at the instant of the collision are trapped and forced to expand as the hole of
the doughnut grows, after the collision of the brane. This can happen similarly with more dimensions, for example in a three-dimensional brane hitting itself along a string.

But because of the special symmetries of string theory, there need to be a total of nine spatial dimensions, three of which are in the brane and are able to get stretched, and the others may be the bulk or may be dimensions that remain wrapped up at the Planck scale; and at the same time, in order for the particle properties and gauge interactions to come out right, the universe must have two holes, which means the brane has collided with itself in two places, in which case one of the many possible vacua of string theory is the one that is right for us. All the details cannot be explained here; but in any case, because the stringbohtyk model is based on string theory, it is a theory of everything, that is to say, it can explain everything that has ever been, is, and will ever be.

So, the universe is a brane that is like the surface of a doughnut with two holes, not just one. And this can be thought of as the shape of a funnel, where the brane is the surface and there is a closed bulk (the plastic or aluminum that makes a funnel) and an open bulk (the space around the funnel). The closed bulk may be very thin so that locally it looks like the two branes separated by a small distance, like in the cyclic model. Some strings contained in the brane may have been trapped around either one of the holes when the collisions occurred, and the universe is full of them with all possible combinations. Figure 1 illustrates the shape of the universe in the stringbohtyk model; our brane is both the inner and outer surface of the funnel (these surfaces should join smoothly at the top and bottom of the funnel even though it is not shown in the figure). One hole is the bulk inside the funnel and the other is at the handle. So the trapped strings go either around the funnel, or around the handle.

3. Prediction for the cosmological constant

It turns out that, due to a special symmetry that arises in the stringbohtyk model, there is a cancellation of all the contributions to the vacuum energy density coming from the usual strings in the brane with the strings that are trapped around a hole. If it were not for the topological holes, the cosmological constant would not get cancelled and it would be of order the Planck density. But because of the holes, the cancellation occurs and the universe can exist for much longer than a Planck time. After very long calculations, one finds that even with the holes there are high-order terms for the vacuum energy density which do not cancel, due to particles of spin 1/2 in the three families, which come out depending on the rest-mass of each particle in the three families, all multiplied together, like this: \((m_{i1}m_{i2}m_{i3})^n/n!\), where the number says which family the particle belongs to, \(n\) is the number of topological holes in the universe, and the \(i\) represents the type of particle, and we
use Planck units. So, the most important contribution to the cosmological constant comes from leptons. The neutrinos have much smaller masses and their contribution is negligible, and the three colors of the quarks make them contribute a term going as the cube power of their multiplied masses, so they are negligible too.

So, the predicted value of the cosmological constant is \((m_e m_\mu m_\tau)^2/2\), where the masses are those of the electron, muon and tau particle, and we have used \(n = 2\). With all the units put back into the equation, the stringbohtyk prediction for the cosmological constant is

\[
\rho_\Lambda = \frac{3H_0^2 \Omega_\Lambda}{8\pi G \rho_{Pl}} = \frac{(m_e m_\mu m_\tau)^2}{2m_{Pl}^6}.
\]  

(2)

Here, \(H_0\) and \(\Omega_\Lambda\) are the things familiar to astronomers, the Hubble constant and the density of the cosmological constant in units of the critical density, and \(m_{Pl}\) and \(\rho_{Pl}\) are the Planck mass and Planck density: \(m_{Pl} = (\hbar c/G)^{1/2} = 2.177 \times 10^{-5} \text{ g}\), and \(\rho_{Pl} = c^5/(\hbar G^2) = 5.16 \times 10^{93} \text{ g cm}^{-3}\). The particle masses are (e.g., Eidelman et al. 2004), \(m_e = 9.109 \times 10^{-28} \text{ g}\), \(m_\mu = 1.883 \times 10^{-25} \text{ g}\), \(m_\tau = 3.168 \times 10^{-24} \text{ g}\), so the predicted value of the density of the cosmological constant in Planck units is

\[
\frac{(m_e m_\mu m_\tau)^2}{2m_{Pl}^6} = 1.388 \times 10^{-123}.
\]  

(3)

The largest error of the particle masses is for the \(\tau\) particle, which implies an error on this prediction of less than one part in a thousand. The measured cosmological constant, using values \(H_0 = 100h_0 \text{ km s}^{-1} / \text{Mpc}^{-1} = 73 \pm 3 \text{ km s}^{-1} / \text{Mpc}^{-1}\), \((1 - \Omega_\Lambda)h_0^2 = 0.13 \pm 0.01\) (Spergel et al. 2006), is

\[
\frac{3H_0^2 \Omega_\Lambda}{8\pi G \rho_{Pl}^{-1}} = (1.48 \pm 0.16) \times 10^{-123}.
\]  

(4)

The good news for astronomy is that there is now an added value to measuring the Hubble constant more accurately, namely to see if the stringbohtyk prediction holds up.

4. Solution to the coincidence problem

So, the stringbohtyk prediction turns out to work, at least for now. But, how is the problem of the coincidence explained? Do we simply have to assume that there is a theoretical prediction for the epoch when the acceleration starts, and we happen by chance to live at this epoch, or can we understand this thing better?

Decades ago, Professor P.A.M. Dirac also noticed another funny coincidence in our universe (Dirac 1937). The ratio of the electric to the gravitational force between an electron
and a proton is

\[ R_{ge} = \frac{e^2}{Gm_p m_e} = 2.27 \times 10^{39} . \] (5)

Also, the number of baryons within the observable horizon is equal to (using for now an Einstein-de Sitter universe for simplicity, with Hubble constant \( H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1} \) and \( \Omega_b = 0.04 \))

\[ N_p = \frac{4\pi^2 \Omega_b}{H_0 G m_p} = 1.63 \times 10^{79} . \] (6)

Professor PAM noticed with curiosity that these big numbers of the universe, one related to fundamental physics and the other to the epoch when we are observing the universe, seem to be roughly related as \( N_p \sim R_{ge}^2 \), and this was a strange coincidence indeed.

A few decades later, Professor Bob Dicke pointed out that this was actually no coincidence (Dicke 1961). Given the facts that the (supposedly) intelligent beings observing the universe arose on a planet supplied with the light from a star, and that the time it took for these beings to evolve is not much smaller than the stellar lifetime, it is not surprising that the first opportunities for these beings to appear in the universe would occur when the age of the universe is of the same order as the stellar lifetime. This is in any case a coincidence that we know is true for us: the Sun’s lifetime is \( 10^{10} \) years, roughly the same as the present age of the universe. So this must imply a relation between some fundamental constants and the present age of the universe.

To derive this relation, we note first that in a star in hydrostatic equilibrium that has a characteristic internal pressure \( p \), with contributions from gas pressure \( p_g = (1 - \beta)p \) and from radiation pressure \( p_{rad} = \beta p \), a fraction \( \beta \) of the hydrostatic support against gravity needs to be provided by the radiation pressure. Therefore, if the opacity is dominated by electron scattering, the luminosity of the star needs to be \( L \sim \beta L_{Edd} \) (where \( L_{Edd} \) is the Eddington luminosity), because by definition when the luminosity is equal to the Eddington one, the radiation pressure exactly balances gravity. In general, a star may have other contributions to the opacity (e.g., free-free and bound-free transitions with heavy ions), and then the luminosity will be further reduced. So in general, the luminosity of a star is \( L = \ell L_{Edd} \), where \( \ell = (\kappa_e/\bar{\kappa})\beta \), \( \kappa_e \) is the electron scattering opacity, and \( \bar{\kappa} \) is a sort of average effective opacity in the stellar interior. In general, \( \ell \) increases with stellar mass. For very massive stars \( \ell \) is close to one, and for low-mass stars \( \ell \) is small (for the Sun, \( \ell \approx 10^{-4.6} \), and for an object at the borderline between stars and brown dwarfs, \( \ell \approx 10^{-7} \)), so its value depends on complex biology determining the mass of the star that is most appropriate for harboring a planet with life. The Eddington luminosity is given by

\[ L_{Edd} = \frac{4\pi c G \mu_e}{\sigma_e} \frac{M}{2\hbar^2 \alpha^2} \frac{3 c^3 G \mu_e m_e^2}{M} , \] (7)
where $\mu_e$ is the mean mass per electron (equal to $1.2m_p$ for the fully ionized primordial mixture of hydrogen and helium), and $\alpha$ is the fine structure constant. If the star converts a fraction $\epsilon$ of its rest-mass energy into radiation over its lifetime, then its lifetime is

$$t_s = \frac{M\epsilon c^2}{L} = \frac{2\alpha^2\epsilon}{3\ell} \frac{m_{pl}^3}{\mu_e m_e^2} t_{pl},$$

where $m_{pl}$ and $t_{pl}$ are the Planck mass and Planck time.

Now, the number of baryons in the universe (eq. [6]) can be reexpressed as

$$N_p = \frac{\Omega_b}{H_0 t_s} \frac{4c^3 t_s}{G m_p} = \frac{\Omega_b}{H_0 t_s} \frac{8\alpha^2\epsilon}{3\ell} \frac{m_{pl}^4}{\mu_e m_e^2 m_p} = \frac{\Omega_b}{H_0 t_s} \frac{8\epsilon}{3\ell} m_p R_{ge}^2.$$

The dimensionless numbers relating $N_p$ and $R_{ge}^2$ can naturally be expected to be not far from unity. Hence this shows that the coincidence of the big numbers of Professor PAM is actually not surprising, but it is simply a consequence of living next to a star that has lived and will live for a time not so different from the present age of the universe.

But now, we see that the reason the acceleration of the expansion is starting just today is the same one. The time when the universe expansion starts accelerating, using equation (2), is

$$t \simeq \left( \frac{3}{8\pi G \rho_\Lambda} \right)^{1/2} = \sqrt{\frac{3}{4\pi}} \frac{m_{pl}^3}{m_e m_\mu m_\tau} t_{pl}.$$

The ratio of this time to the lifetime of the star (eq. 8) is

$$\frac{t}{t_s} \simeq \frac{3\sqrt{3} \ell \mu_e m_e}{4\sqrt{\pi} \alpha^2 \epsilon m_\mu m_\tau}.$$

This solves the coincidence problem of the cosmological constant. That is to say, the stryn-bohtytk prediction that the cosmological constant density scales as the sixth power of the ratio of typical particle masses to the Planck mass (eq. (2)) implies that the coincidence of the age of the universe at the time the acceleration starts with the present age is a necessity. Of course, to make this coincidence more outstanding, it is still necessary that the combination of dimensionless constants appearing in equation (11) turns out to be close to unity. The value of these constants depends on highly complex and diverse physics: the strength of the electromagnetic interaction, the ratio of the mass of leptons to the proton mass, stellar physics, and the complex biology that affects which stellar mass is most appropriate for life. However, because these constants are not different from unity by too many orders of magnitude, it makes us feel better to say that the combination in equation (11) just happens to be close to unity by pure coincidence, than in the case when we did not have the big numbers of the universe cancelling out.
5. Discussion

Such is the bewilderment caused by the detection of an accelerated expansion, that most astronomers in the world, leaving aside any other more mundane astrophysics, are focusing their efforts and proposals into methods to find out something else about “dark energy”, whatever it may be.

The stryngbohtyk model has been proposed in this paper, in which the universe is a brane with funnel shape in the nine-dimensional space of string theory, where some dimensions got curled up at the Planck scale to make all the observed particles and gauge interactions from strings that are confined to the funnel brane (with the familiar three extended dimensions), which lives in the bulk (which has the rest of the dimensions), after selection of one among many possible vacua. As in the cyclic model, there is a brane collision giving rise to the Big Bang. In the cyclic model, there are two plane-parallel, infinite branes that collide. But in the stryngbohtyk model, the brane collides with itself, the collision can puncture the brane changing its topology, and strings get trapped around the created hole and are forced to expand as an epoch of inflation gets going. Today, we live in a very small patch of the brane with funnel shape and we cannot realise the true topology of the universe. The primordial perturbations are homogeneous as in inflation, and there are no monopoles or primordial black holes. This is, by the way, truly a pity, because if evaporating black holes could be discovered, Stephen Hawking would get his Nobel prize.

Curiously, the stryngbohtyk model makes a prediction, obtained with stryngbohtyk reasoning, of the exact value of the cosmological constant, in terms of the lepton masses, which matches the observation.

Not only that. In fact, any model, stryngbohtyk or not, in which the cosmological constant has a reason to be $\rho_\Lambda \sim R_{ge}^3$, where $R_{ge}$ is Dirac’s ”big number” of the universe (the ratio of the electromagnetic to gravitational forces between electrons and protons), has the nice implication that the coincidence of our time with the time when the universe gets a wish to accelerate is a necessity, basically for the same reason why it is a necessity that the number of protons in the present observable horizon is about the same as the square of $R_{ge}$, hence saving us from anthropic headaches. So, perhaps this cosmological constant is not so ugly after all.

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REFERENCES

Dicke, R. H. 1961, Nature, 192, 440

Dirac, P. A. M. 1937, Nature, 139, 323

Eidelman, S., et al., 2004, Phys. Let. B, 592, 1 (http://pdg.lbl.gov).

Riess, A. G., et al. 2006, astro-ph/0611572

Spergel, D. N., et al. 2006, astro-ph/0603449

Steinhardt, P. J., & Turok, N. 2005, NewAR, 49, 43

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Fig. 1.— Shape of the universe according to the stryngbohtyk model. Our universe is a brane with the shape of the surface of the funnel (both inner and outer surface, connected on the high curvature regions at the edges, not shown in the figure), and the particles and forces we observe are strings confined in the brane. There is an inner closed bulk and an outer bulk, and the universe has two topological holes. For better inspiration to think on the stryngbohtyk model, it is recommended to place an object as shown in the figure on top of one’s head.