How to create a universe

Gordon McCabe

February 27, 2007

Abstract

The purpose of this paper is (i) to expound the specification of a universe, according to those parts of mathematical physics which have been experimentally and observationally verified in our own universe; and (ii) to expound the possible means of creating a universe in the laboratory.

1 Universe specification

According to modern mathematical theoretical physics, the specification of a physical universe can be broken down into the following:

1. Specify a space-time.
2. Specify a set of gauge fields.
3. Specify a set of elementary particles, and partition them into a finite number of generations.
4. Specify the strengths of the gauge fields.
5. Specify the couplings between the gauge fields and the elementary particles.
6. Specify the direct ('Yukawa') couplings between elementary particles.
7. Specify the mixing between the elementary particles in different generations.
8. Specify cosmological parameters corresponding to the initial conditions for the universe.

This list is based upon the understanding gleaned from general relativistic cosmology and the standard model of particle physics, the latter being an application of quantum field theory. Both these theories are empirically verified. I do not intend to consider how one might define a physical universe according to speculative theories such as string theory or supersymmetry. Note also that these specifications are not necessarily independent; for example, the parameters required to uniquely specify an elementary particle include those which specify its coupling to the gravitational field and the gauge fields (mass, electric charge, weak hypercharge etc.), and parameters which depend upon the dimension and signature of space-time (spin, parity etc.).

Each one of the specifications above involves making a choice from a huge range of possibilities on offer. As a consequence, there exists a huge set of possible physical universes. In this paper, we will approach the notion of possible physical universes using the philosophical doctrine of 'structural realism', which asserts that, in mathematical physics at least, the physical domain of a true theory is an instance of a mathematical structure. It follows that if the domain of a true theory extends to the entire physical universe, then the entire universe is an instance of a mathematical structure. Equivalently, it is asserted that the physical universe is isomorphic to a mathematical structure.

In terms of the specifications above, the mathematical structures are as follows:

1. To specify a space-time, a pseudo-Riemannian manifold $(\mathcal{M}, g)$ of a particular dimension n and signature (p, q) is specified.

2. To specify a gauge field, a compact connected Lie group G is specified. This is called the gauge group of the field.

3. To specify a set of elementary particles, and their partition into a finite number of generations, a finite family of irreducible unitary representations of the local space-time symmetry group $\mathscr{P}$ is specified.

4. To specify the strength of a gauge field with gauge group G, a choice of adjoint-invariant metric is specified in the Lie algebra $\mathfrak{g}$.

5. To specify the couplings between the gauge fields and the elementary particles, the values of the 'charges' possessed by elementary particles are specified by means of finite-dimensional irreducible representations of the gauge groups of the corresponding gauge fields.

6. To specify the direct ('Yukawa') couplings between elementary particles, Yukawa matrices are specified.

7. To specify the mixing between the elementary particles in different generations, matrices such as the Cabibbo-Kobayashi-Maskawa matrix are specified.

8. To specify cosmological parameters corresponding to the initial conditions for the universe, the space-time $(\mathcal{M}, g)$ is taken to be a product manifold $\mathbb{R} \times \Sigma$, the global symmetry group (or Killing Lie algebra) of 3-dimensional space Σ is specified, and the dynamical parameters which determine the time evolution of the 3-dimensional geometry, such as the Hubble parameter H_0 and density parameter Ω_0, are specified.

Our own physical universe is specified as follows:

1. Space-time is a 4-dimensional pseudo-Riemannian manifold $(\mathcal{M}, g)$ of signature $(3, 1)$.

2. There are three force fields: the strong nuclear force, the weak nuclear force, and the electromagnetic force. The weak and electromagnetic fields are unified in the electroweak gauge field. The gauge group of the strong force is $SU(3)$; the gauge group of the electroweak force is $U(2) \cong SU(2) \times U(1)/\mathbb{Z}_2$, and the gauge group of the electromagnetic force is $U(1)$.

3. The elementary particles consist of quarks, leptons and gauge bosons. Elementary particles are divided into fermions and bosons according to the value they possess of a property called 'intrinsic spin'. If a particle possesses a non-integral value of intrinsic spin, it is referred to as a fermion, whilst if it possesses an integral value, it is referred to as a boson. The particles of the elementary matter fields are fermions and the interaction carriers of the gauge force fields are bosons. The elementary fermions come in two types: leptons and quarks. Whilst quarks interact via both the strong and electroweak forces, leptons interact via the electroweak force only. There are six types of lepton and six types of quark. The six leptons consist of the electron and electron-neutrino (e, ν_e), the muon and muon-neutrino (μ, ν_μ), and the tauon and tauon-neutrino (τ, ν_τ). The six quarks consist of the up-quark and down-quark (u, d), the charm-quark and strange-quark (c, s), and the top-quark and bottom-quark (t, b). The six leptons have six anti-leptons, $(e^+, \overline{\nu}_e)$, $(\mu^+, \overline{\nu}_\mu)$, $(\tau^+, \overline{\nu}_\tau)$, and the six quarks have six anti-quarks $(\overline{u}, \overline{d})$, $(\overline{c}, \overline{s})$, $(\overline{t}, \overline{b})$. The masses of the elementary fermions are as follows:[1]

m_e	Electron mass	(510998.92 ± 0.04)eV
m_μ	Muon mass	(105658369 ± 9)eV
m_τ	Tauon mass	(1776.99 ± 0.29)MeV
m_u	Up quark mass	$(1.5 - 4)$MeV
m_d	Down quark mass	$(4 - 8)$MeV
m_c	Charm quark mass	$(1.15 - 1.35)$GeV
m_s	Strange quark mass	$(80 - 130)$MeV
m_t	Top quark mass	(174.3 ± 5.1)GeV
m_b	Bottom quark mass	$(4.1 - 4.9)$GeV
m_{ν_e}	Electron neutrino mass	< 3eV
m_{ν_μ}	Muon neutrino mass	< 0.19MeV
m_{ν_τ}	Tau neutrino mass	< 18.2GeV

4. To specify the strength of a gauge field with gauge group G, a choice of adjoint-invariant metric is specified in the Lie algebra $\mathfrak{g}$. The degrees of freedom available in the choice of this metric correspond to what physicists call the 'coupling constants' of the gauge field. In the case of a gauge field with a simple gauge group, there is a single degree of freedom in the choice

[1] All the parameter values and estimates in this paper are taken from Tegmark *et al* 2005.

of the adjoint-invariant metric upon the corresponding Lie algebra, hence there is a single coupling constant. For a gauge field with a more general compact gauge group G, there is a coupling constant for every simple Lie algebra and every copy of $\mathfrak{u}(1)$ in a direct sum decomposition of the Lie algebra $\mathfrak{g}$. The gauge group of the electromagnetic field is $U(1)$, hence there is a single electromagnetic coupling constant, determined by q, the charge of the electron. The gauge group of the strong force, $SU(3)$, is simple, hence the strong force also has a single coupling constant, g_s. In the case of the electroweak force, with gauge group $U(2) \cong SU(2)_L \times U(1)_Y/\mathbb{Z}_2$, there are two coupling constants: g, the weak isospin coupling constant, associated with $SU(2)_L$, and g', the weak hypercharge coupling constant, associated with $U(1)_Y$. Alternatively, one can specify the metric on $\mathfrak{u}(2)$ with a combination of the Weinberg angle θ_W, and the charge of the electron q. These parameters are related by the expressions $g = q/\sin\theta_W$ and $g' = q/\cos\theta_W$.

g	Weak isospin coupling constant at m_Z	0.6520 ± 0.0001
θ_W	Weinberg angle	0.48290 ± 0.00005
g_s	Strong coupling constant at m_Z	1.221 ± 0.022

5. To specify the couplings between the gauge fields and the elementary particles, the values of the 'charges' possessed by elementary particles are specified. For example, in the case of couplings between particles and the electromagnetic force, the strength of the coupling is determined by the electromagnetic charge of the particle. In general, the charges of an elementary particle correspond to the irreducible representation of $SU(3) \times SU(2) \times U(1)$ with which that particle is associated. Particles which lack a certain type of charge will not couple at all to the corresponding gauge field.

6. In the case of a universe with spontaneous symmetry breaking caused by Higgs fields, the Yukawa couplings specify the direct interactions between the Higgs bosons and the elementary fermions. The nature of these interactions are specified by trilinear invariant forms upon the typical fibre of tensor product bundles such as $\iota\sigma_L \otimes \iota \otimes (\Lambda^2\bar{\iota})\overline{\sigma}_R$ (Derdzinski p188), where σ_L is a left-handed Weyl spinor bundle, σ_R is a right-handed Weyl spinor bundle, and ι is an electroweak interaction bundle, a complex plane bundle. The coefficients which specify these trilinear forms are the Yukawa couplings, and these couplings are often organised into Yukawa matrices. The masses of the elementary fermions are related to the Yukawa coupling coefficients, listed as follows:

G_e	Electron Yukawa coupling	2.94×10^{-6}
G_μ	Muon Yukawa coupling	0.000607
G_τ	Tauon Yukawa coupling	0.0102156233
G_u	Up quark Yukawa coupling	0.000016 ± 0.000007
G_d	Down quark Yukawa coupling	0.00003 ± 0.00002
G_c	Charm quark Yukawa coupling	0.0072 ± 0.0006
G_s	Strange quark Yukawa coupling	0.0006 ± 0.0002
G_t	Top quark Yukawa coupling	1.002 ± 0.029
G_b	Bottom quark Yukawa coupling	0.026 ± 0.003
G_{ν_e}	Electron neutrino Yukawa coupling	$< 1.7 \times 10^{-11}$
G_{ν_μ}	Muon neutrino Yukawa coupling	$< 1.1 \times 10^{-6}$
G_{ν_τ}	Tau neutrino Yukawa coupling	< 0.10

The electroweak Higgs field ϕ itself requires two parameters, λ and μ, for its specification, and these parameters determine the masses of the Higgs bosons and the electroweak gauge bosons.

μ^2	Quadratic Higgs coefficient	$\sim -10^{-33}$
λ	Quartic Higgs coefficient	$\sim 1?$

7. The mixing between the quarks in different generations is specified by the Cabibbo-Kobayashi-Maskawa (CKM) matrix. By convention, the mixing is expressed in terms of the $\{d, s, b\}$ quark flavours. The bundle which represents the generalisation of these three quark flavours is $\sigma_d \oplus \sigma_s \oplus \sigma_b$, where each summand is a copy of the Dirac spinor bundle σ. Different mixtures of these flavours correspond to different orthogonal decompositions $\sigma_{d'} \oplus \sigma_{s'} \oplus \sigma_{b'}$. Each such decomposition is defined by the Cabibbo-Kobayashi-Maskawa matrix, which can be specified by four parameters, $\{\theta_{12}, \theta_{23}, \theta_{13}, u\}$, called the Cabibbo-Kobayashi-Maskawa parameters. The first three parameters $\theta_{12}, \theta_{23}, \theta_{13}$ are angular parameters with values in $[0, \frac{\pi}{2}]$. The fourth parameter is a phase factor $u = e^{i\delta}$, (Derdzinski 1992, p160). This notion of quark mixing is considered to be a consequence of the interaction of quarks with the electroweak Higgs bosons. If, as current evidence indicates, the neutrinos possess mass, then there is a corresponding notion of lepton mixing, and the CKM matrix has a lepton counterpart called the Maki-Nakagawa-Sakata (MNS) matrix. This matrix also requires four parameters for its specification.

$\sin\theta_{12}$	Quark CKM matrix angle	0.2243 ± 0.0016
$\sin\theta_{23}$	Quark CKM matrix angle	0.0413 ± 0.0015
$\sin\theta_{13}$	Quark CKM matrix angle	0.0037 ± 0.0005
δ_{13}	Quark CKM matrix phase	1.05 ± 0.24
$\sin\theta'_{12}$	Neutrino MNS matrix angle	0.55 ± 0.06
$\sin\theta'_{23}$	Neutrino MNS matrix angle	≥ 0.94
$\sin\theta'_{13}$	Neutrino MNS matrix angle	≤ 0.22
δ'_{13}	Neutrino MNS matrix phase	?

8. 3-dimensional space on cosmological scales is currently thought to be well-approximated by $\mathbb{R}^3$, with $H_0 \approx (10 \text{ Gyr})^{-1}$ and $\Omega_0 = 1.01 \pm 0.02$.

2 Universe creation in a laboratory

Inflationary cosmology postulates that there was a period in our universe's early history during which gravitation became effectively repulsive, and the universe consequently underwent exponential expansion (see Blau and Guth, 1987). Under inflationary expansion, the energy density ρ is positive and constant in time, but the pressure is negative $p = -\rho$. This is said to be the 'false vacuum' state. Now, one of the most intriguing possibilities opened up by inflation, is the possible creation of a universe 'in a laboratory'. Creation in a laboratory is taken to mean the creation of a physical universe, by design, using the 'artificial' means available to an intelligent species. It is the ability of inflation to maintain a constant energy density, in combination with a period of exponential expansion, which is the key to these laboratory creation scenarios. The idea is to use a small amount of matter in the laboratory, and induce it to undergo inflation until its volume is comparable to that of our own observable universe. The energy density of the inflating region remains constant, and because it becomes the energy density of a huge region, the inflating region acquires a huge total (non-gravitational) energy.

The original proposals for universe creation in a laboratory, made in the late 1980s, suggested the use of false vacuum 'bubbles'. A more recent approach suggests the use of magnetic monopoles. Let us consider each approach in turn.

In Farhi and Guth (1987), the creation of an inflationary universe in the laboratory was considered to be a special case of the behaviour of false vacuum bubbles. A false vacuum bubble is a region of such vacuum surrounded by true vacuum. The study of false vacuum bubbles made by Blau *et al* (1987) forms the basis of the Farhi-Guth proposal. In these models, they consider, for simplicity, a false vacuum bubble to occupy, spatially, the interior of a solid ball $\mathbb{D}^3$. In space-time, such a false vacuum bubble would occupy the interior of a solid hyper-cylinder $\mathbb{R}^1 \times \mathbb{D}^3$. Blau *et al* consider a false vacuum bubble to be surrounded by spherically symmetric, zero energy density true vacuum. A 'thin wall' separates the false vacuum from the infinite region of true vacuum. A false vacuum bubble of radius above a certain critical value will undergo inflation. The assumption that the exterior region is spherically symmetric and empty, entails that it must be a portion of the maximally extended Schwarzschild-Kruskal black hole space-time. From this, Farhi and Guth infer that "the creation of a universe is necessarily associated with the production of a black hole," (Farhi and Guth, 1987, p150). According to Farhi and Guth, the created universe resides inside the event horizon of a black hole, but appears to be a region of inflating false vacuum from the inside.

The Schwarzschild-Kruskal space-time has topology $\mathbb{R}^2 \times S^2$. Diagrammatically, it is often represented by the Kruskal diagram, in which the spherical dimensions are suppressed, and only the geometry on $\mathbb{R}^2$ is delineated. The paper of Blau *et al* provides the means to smoothly join an inflating region of false vacuum to a portion of Schwarzschild-Kruskal space-time. The interface between the two regions is described by a curve in the Kruskal diagram. Each point of the Kruskal diagram corresponds to a 2-sphere in the 4-dimensional space-time, hence a curve in the Kruskal diagram corresponds to a hyper-cylinder $\mathbb{R}^1 \times S^2$ in the 4-dimensional space-time. As depicted in Figure 1, with the Kruskal diagram oriented so that the null curves lie at 45 deg to the vertical, one removes from the diagram the region which lies to the left of the interface-curve, and one attaches the interior of the inflating false vacuum bubble in its place. The inflating false vacuum bubble has the space-time topology $\mathbb{R}^1 \times \mathbb{D}^3$, and one joins the $\mathbb{R}^1 \times S^2$ boundary of the bubble to the $\mathbb{R}^1 \times S^2$ boundary of the remaining Schwarzschild-Kruskal space-time.

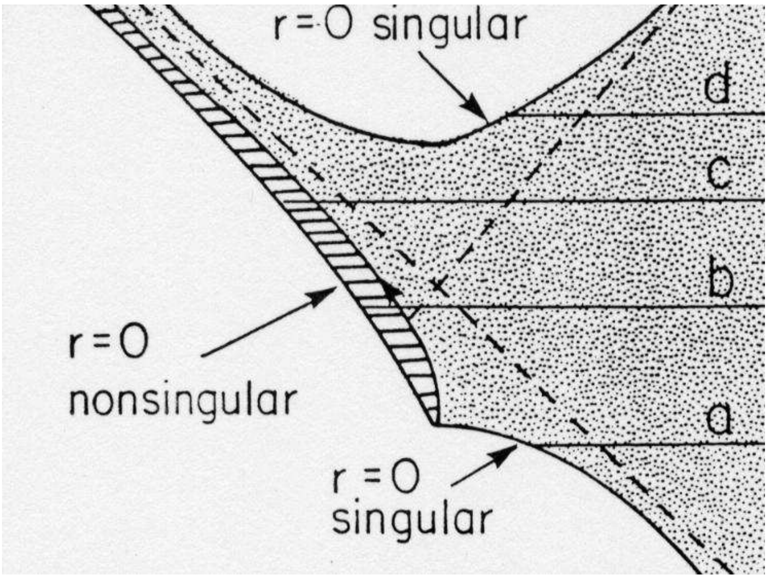

Figure 1: Space-time diagram of a false vacuum bubble inside a Schwarzschild black hole, from Guth (1991), p239.

Blau *et al* then introduce a preferential foliation of the resulting space-time. This foliation is depicted as a horizontal slicing of the doctored Kruskal diagram. The corresponding foliation of the undoctored Kruskal diagram yields the Einstein-Rosen bridge, a non-traversable wormhole.

Running through the leafs of the foliation, as depicted in Figures 1 and 2, one begins with a region of space which is asymptotically flat at large distances, but which contains a gravitational 'sink' inside the Schwarzschild radius at $r = 2M$. A finite region of false vacuum then appears inside the Schwarzschild radius, and in successive leafs of the foliation, it mushrooms in size. The bubble grows, however, on what would have been the white hole side of the Einstein-Rosen bridge. As Guth puts it "the swelling takes place by the production of new space;

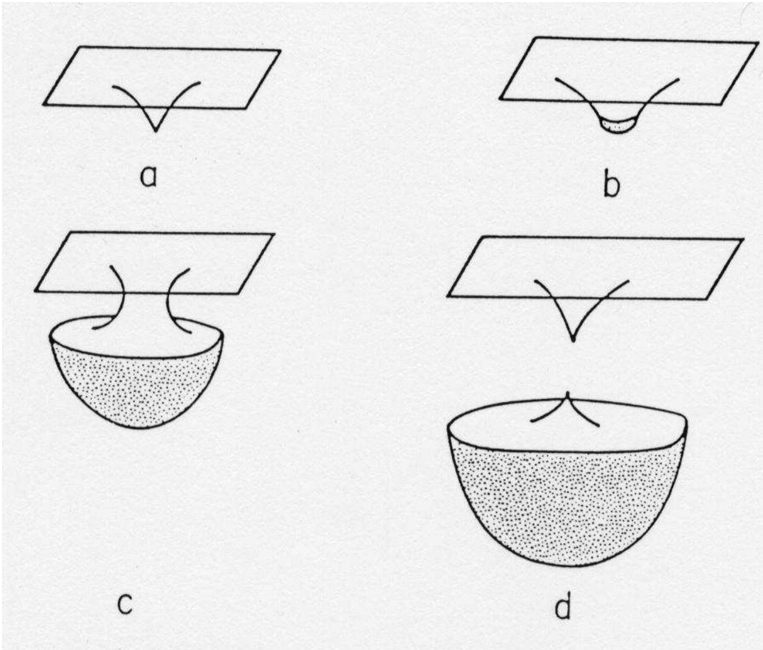

Figure 2: False vacuum bubble detaching from its parent, from Guth (1991), p240.

the plane of the original space is unaffected." (Guth 1991, p239-240). Running through the foliation, there is a similar 'pinching off' effect to that encountered by the Einstein-Rosen bridge. The inflating bubble separates from the rest of space like a rain drop which hangs from the gable of a window, elongates, and then detaches itself. Under this particular foliation, the spatial slices become disconnected, one component consisting of the inflating bubble, the other consisting of the throat of a black hole and the surrounding, asymptotically flat space. An expanding false vacuum child universe is spatially connected to a parent universe for a short time, before the umbilical cord is severed, and the parent becomes spatially disconnected from the child. Guth states that the false vacuum bubble "completely disconnects from the original space-time, forming a new, isolated closed universe." (Guth 1991, p240). Although the child universe does indeed become spatially disconnected from the parent universe after a period of time, the *space-time* is very much connected; it is merely the spacelike hypersurfaces along one particular foliation which become disconnected. Because the Einstein-Rosen bridge is a non-traversable wormhole, once the child universe has begun to inflate, it is causally disconnected from the parent universe. The inflating bubble of false vacuum resides in the white hole part of the Kruskal diagram, and there is no timelike or null curve from the black hole region to the white hole region.

One might infer that the creation of a child universe is confined to the interior of a black hole to prevent the laboratory from being engulfed by the expansion of the new universe. This, however, is not correct, for even if an inflating false vacuum bubble were to be created outside a black hole, it would not expand to engulf the creator and his laboratory. The region of false vacuum would have negative pressure, and would therefore be at lower pressure than its surroundings. As Guth states, for an observer in the exterior region, "the pressure gradient would point inward and the observer would not expect to see the region increase in size." (Guth 1991, p238).

Farhi and Guth are not troubled by the prospect of a child universe created inside the Schwarzschild radius of a black hole. They state that it "does not in principle present an insurmountable obstacle" (Farhi and Guth, p150) to the creation of a universe by man-made processes. They argue that "ordinary materials (e.g. stars) can collapse to form black holes, and it is possible at least to conceive of a laboratory setup that would produce a black hole," (ibid.). However, they point out that on a classical level, the creation of an inflationary universe in the laboratory requires the presence of an initial singularity. This is a serious obstacle because, as Guth puts it, "although an initial singularity is often hypothesized to have been present at the big bang, there do not appear to be any singularities available today." (Guth 1991, p240).

In the doctored Kruskal diagram, it is the white hole singularity which is present in the early slices of the foliation, and which provides the initial singularity. The final singularity of the doctored Kruskal diagram is not an impediment as it is something which could be created as a consequence of the universe-creation process. The difficulty with an initial singularity is that it would be a necessary precursor to the creation of a child universe.

The presence of an initial singularity does not follow from the supposition that child universe creation takes place within a black hole/white hole spacetime; it follows from modelling the false vacuum bubble as a part of de Sitter spacetime. Farhi and Guth use a reverse version of Penrose's 1965 singularity theorem to establish their claim; this version deals with past trapped surfaces rather than the future trapped surfaces which are the hallmark of gravitational collapse. Farhi and Guth refer to the past-trapped surfaces as 'anti-trapped' surfaces. A sufficiently large false vacuum bubble will contain anti-trapped two-spheres. Farhi and Guth use the theorem:

A space-time $(\mathcal{M}, g)$ contains an initial singularity if

1. The null-convergence condition is satisfied: $Ric(v, v) \geq 0$ for all null vectors v.

2. There exists a non-compact Cauchy hypersurface in $(\mathcal{M}, g)$.

3. There exists an anti-trapped compact surface in $(\mathcal{M}, g)$.

Farhi and Guth (p154) argue that prior to the compression required for universe creation, the laboratory space-time would be closely approximated by Minkowski space-time. They infer from this that condition 2) would be satisfied.

Condition 1) is equivalent to the 'very weak' energy condition, $T(v,v) \geq 0$ for any null vector v. If the weak energy condition is satisfied, it entails that the very weak energy condition must be satisfied. Farhi and Guth point out that the weak energy condition, hence the very weak energy condition, is satisfied by all standard classical models of matter fields. They show that in the spherically symmetric idealization, condition 3) is satisfied, hence there must be an initial singularity. They also provide good reasons for believing that even a lack of spherical symmetry cannot avoid anti-trapped surfaces and an initial singularity.

It must be emphasised again that the initial singularity is not a consequence of the assumption that a man-made universe must be embedded inside a black hole space-time. In the doctored Kruskal diagram, the two-spheres represented by points inside the white hole region are indeed past-trapped ('anti-trapped'), but it is the past-trapped two-spheres of the inflating false-vacuum bubble which entail the initial singularity. An inflating false vacuum bubble which is not surrounded by $Ric = 0$ true vacuum, but by the more realistic matter fields of a laboratory, would still require an initial singularity.

The belief that the creation of a child universe cannot be achieved classically, prompted the suggestion that it could be achieved by quantum tunnelling instead. It was suggested that a false vacuum bubble of radius below the critical value for inflation, but free from an initial singularity, might be able to quantum mechanically tunnel into an inflationary state (see Ansoldi and Guendelman 2006, for details and references). More generally, certain quantum effects seem to suggest that the energy conditions of general relativity can be violated. Farhi and Guth (p154) allude to the fact that quantum field theory in curved space-time generally violates the very weak energy condition, and this implies that the creation of a child universe could occur without an initial singularity.

Whilst the original idea for universe creation in a laboratory proposed a false-vacuum bubble, represented as part of de Sitter space-time, embedded inside the maximally extended Schwarzschild-Kruskal spacetime, Sakai *et al* (2006) imagine a magnetic monopole, also represented as part of de Sitter space-time, but embedded inside maximally extended Reissner-Nordström space-time. To be more precise, a part of de Sitter space-time is joined to a part of the maximally extended Reissner-Nordström space-time for the case where the mass exceeds the charge, $q < M$. Sakai *et al* show that a classically stable monopole could evolve into an inflationary universe by a classical process, without quantum tunnelling. If the mass of the monopole exceeds its charge, then it becomes inflationary. Sakai *et al* propose that the accretion or implosion of mass onto an initially stable monopole, be represented by a spherical 'domain wall', surrounding the monopole, which eventually collides with it.

The significance of the maximally extended Reissner-Nordström space-time for $q < M$ is that it includes a timelike singularity which does not belong to the past of the region outside the black hole containing the laboratory. The Reissner-Nordström space-time is specified by the following metric tensor on $\mathbb{R}^2 \times S^2$:

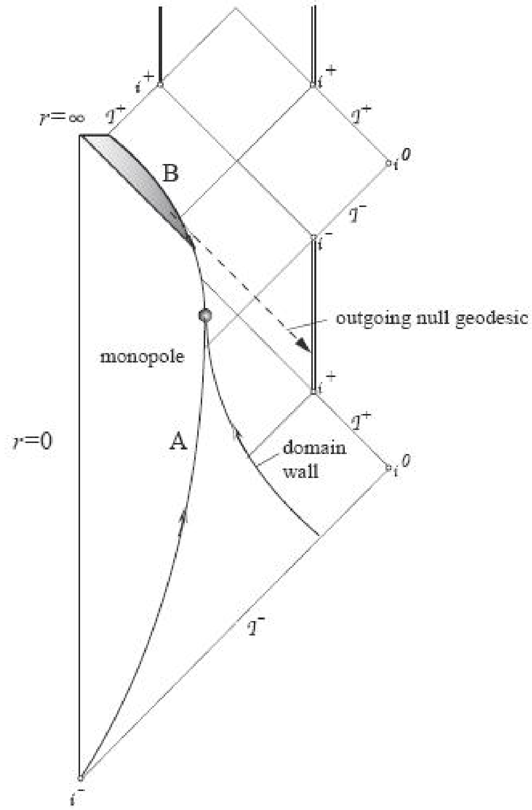

Figure 3: Diagram of an inflating monopole inside a Reissner-Nordström space-time, from Sakai *et al* 2006.

$$ds^2 = -\left(1 - \frac{2M}{r} + \frac{q^2}{r^2}\right) dt \otimes dt + \left(1 - \frac{2M}{r} + \frac{q^2}{r^2}\right)^{-1} dr \otimes dr + r^2 d\Omega^2 \ .$$

$d\Omega^2$, of course, is the standard metric on the 2-sphere. Unlike the Kerr space-time (for a rotating black hole), the Reissner-Nordström space-time doesn't have a ring singularity, and cannot be extended to negative values of r. However, just like the Kerr space-time, it possesses an outer horizon r_+, and an inner horizon r_-:

$$r_\pm = M \pm (M^2 - q^2)^{1/2} \ .$$

These horizons are defined by the roots of the function

$$\Delta = r^2 - 2Mr + q^2 \ ,$$

i.e., the values of r at which Δ is zero. To obtain the maximally extended spacetime, one first partitions the Reissner-Nordström geometry into three distinct blocks: (i) the asymptotically flat block outside the black hole, with $r \in [r_+, \infty)$; (ii) the inter-horizon block, with $r \in [r_-, r_+]$; and (iii) the black hole interior, with $r \in [r_-, 0)$, and the singularity 'at' $r = 0$. The maximally extended spacetime for $q < M$ is obtained by tessellating various copies of these blocks into an infinite chain.

The created inflationary universe depicted in Figure 3 includes past incomplete null geodesics emanating from anti-trapped surfaces, but there is no initial singularity as such. "Although a singularity exists in the past of the inflating monopole, the singularity is located in the future of the experimenter in the laboratory. In other words, even if no singularity exists in the past of the experimenter who makes a monopole, inflation in the monopole is realizable in the future of the experimenter. From a observational point of view, however, since the inflating monopole is realized inside a black hole, the experimenter cannot observe it unless he or she enters into the black hole," (Sakai *et al*, 2006). The inflating monopole could be created by an experimenter whose past is geodesically complete.

Magnetic monopoles are predicted to exist by certain unified field theories, and whilst a magnetic monopole has yet to be discovered, a collision between an electron and a positron could, in principle, create a monopole–anti-monopole pair. Monopoles have masses much greater than those of electrons and positrons, however, and the kinetic energies required to create them by such a collision are beyond the capabilities of contemporary particle accelerators. Universe creation in a laboratory therefore remains beyond current technology, but theoretically possible.

References

[1] Ansoldi, S., Guendelman, E.I. (2006). Child Universes in the Laboratory. arXiv:gr-qc/0611034.

[2] Blau, S.K., Guendelman, E.I., Guth, A.H. (1987). Dynamics of False Vacuum bubbles, *Physical Review* D35, pp1747-1766.

[3] Blau, S.K., Guth, A.H. (1987). Inflationary Cosmology, in *300 Years of Gravitation*, S.W.Hawking and W.Israel (eds.), pp524-603. Cambridge: Cambridge University Press.

[4] Derdzinski, A. (1992). *Geometry of the Standard Model of Elementary Particles*, Texts and Monographs in Physics, Berlin-Heidelberg-New York: Springer Verlag.

[5] Farhi, E., Guth, A.H. (1987). An obstacle to creating a universe in the laboratory, *Physics Letters* B183(2), pp149-155.

[6] Farhi, E., Guth, A.H., Guven, J. (1990). Is it Possible to Create a Universe in the Laboratory by Quantum Tunneling, *Nuclear Physics* B339, pp417-490.

[7] Guth, A.H. (1991). Can a Man-Made Universe be Created by Quantum Tunneling without an Initial Singularity?, *Physica Scripta* Vol T36, pp237-246.

[8] Sakai, N., Nakao, K., Ishihara, H., and Kobayashi, M. (2006). Is it possible to create a universe out of a monopole in the laboratory? *Physical Review* D74(2), 024026.

[9] Tegmark, M., Aguirre, A., Rees, M.J., and Wilczek, F. (2005). Dimensionless constants, cosmology and other dark matters, arXiv:astro-ph/0511774.