The Multiverse — Next Step in Our Growing Understanding of Reality?

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PHYSICS
To understand the whole of reality has been the pursuit of humankind since the appearance of our species. Over the last few thousand years the human perception of physical reality has been transformed through discrete steps. Each paradigm advancement has presented a larger, more grand, creation—a fuller representation of God’s eternal power.
Now the beginning of the new millennium denotes
the commencement of another profound
advancement of humankind’s perception of the
whole of existence and, thus, of the creative nature
of God.

This new paradigm shift is of far greater magnitude
and vastly more comprehensive than all those
preceding.
In this plenary session I summarize the past perceptions of physical reality, and then focus on the scientific and mathematical evidence suggesting a new multiverse paradigm from string/M theory. M theory paints a vastly expanded picture of reality. Its beauty, order, simplicity, and complexity are incomparable.

Then in the first talk in the Multiverse session I will considers some of the philosophical and theological issues raised by the concept of a string theory multiverse. We will have several additional issues and insights raised in the other talks, both pro and con.
3 Story Universe
of the ancient Mideast world
Geocentric Picture of Universe from Greco-Roman until 1600’s
Heliocentric Picture of Universe from 1600’s through 1700’s
Galacticentric Picture of Universe from 1800’s through early 1900’s
1924: Edwin Hubble shows that each galaxy is a collection of stars, just like the Milky Way.
Univercentric Picture of Universe from 1900’s (until 2000’s?)

(Each dot of light is an entire galaxy)
Visible Universe

Visible Universe is 13.7 billion light years in diameter

= 8 x 10^{22} 

Current size is over twice this.

trillion galaxies,

trillion stars per galaxy
What is more: the universe is expanding.

1929: Hubble again, this time showing that the further away a galaxy is, the more rapidly it is moving away from us.

Modern version of Hubble's diagram.

S. Carroll, http://pancake.uchicago.edu/~carroll
If three-dimensional space is represented by a two-dimensional surface, then one model of the expanding universe is reminiscent of a balloon that inflates from nothing. In this model space is finite, but unbounded: an observer in the space could travel freely all around the universe. The dots represent galaxies (or clusters of galaxies). As the universe expands, space stretches, so all the dots move farther apart from all their neighbours. An observer on any one of the dots would see the other dots receding in a systematic pattern, and would seem to be at the centre of this outward migration.
The Univercentric paradigm naturally raised the question of “How came the universe?” The “Big Bang,” answer was eventually fleshed out to include an initial superluminal inflation stage.

In 1997 it was discovered that the universe is now in a second accelerated stage, but much longer and much, much weaker than the initial inflation stage. Best fit to data indicates this stage began around 6 to 7 billion years ago.
What would make the universe accelerate?

Best answer: **Dark Energy.** A form of energy that exists even in empty space (“vacuum energy”).

- **Smoothly distributed** through space: doesn't fall into galaxies and clusters.

- **Constant density** (or changing very slowly) through time. Not diluted by expansion.

- **Invisible** to ordinary matter. Only detected via gravity.

S. Carroll, http://pancake.uchicago.edu/~carroll
Expansion of the Universe

Dark Matter + Dark Energy affect the expansion of the universe

$\Omega_\text{m} \quad \Omega_\text{v}$

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$(10^{-3} \text{ eV})^4$
We therefore seem to have a complete inventory of the stuff of which the universe is made:

- 70% dark energy
- 25% dark matter
- 5% ordinary matter

Seeking simplicity, we are led to astonishing ideas. What will be next?
The 1950’s began a drive to understand the forces of nature within the universe in a consistent, hopefully related manner, which culminated in the 1960’s with the Standard Model of particle interactions, 

\[ SU(3)_C \rightarrow SU(2)_W \rightarrow U(1)_Y, \]

as a quantum mechanical description of the strong and weak nuclear and electromagnetics.
Problem with dark energy: There's not enough!

The vacuum (empty space) is not a quiet place; it roils with the quantum fluctuations of every field in the universe.

These fluctuations should carry energy; we know for a fact that they affect other forces (besides gravity).

A quick back-of-the-envelope calculation reveals:

**theoretical prediction = $10^{120}$ times observation.**

A universe with such a vacuum energy would have been ripped to shreds long ago.

S. Carroll, http://pancake.uchicago.edu/~carroll
In the course of the 20th century we went from knowing almost nothing about the universe to knowing all its basic features.

But knowing is different from understanding.
So we know a great deal:

- **General relativity** (gravity)
- **Standard Model** of particle physics
- **Inventory:** ordinary matter, dark matter, dark energy

But deep puzzles remain:

- **Reconcile** gravity with quantum mechanics?
- What is the **dark matter**?
- What is the **dark energy**? And why so little?

Look for big ideas to tie things together.
Physicists seeking

the Theory of Everything (Physical)

Scientific Understanding of the Universe Sought in String/M Theory

www.baylor.edu/~CASPER

www.inet.hr/~tstimac/artwork.htm
In the 1980’s String Theory offered a means of consistently unifying the non-gravitational forces with gravity, the sole additional force found in our universe. String theory enlarged the Univercentric paradigm from one of 3+1 dimensions (three spatial dimensions and 1 time dimension) to one of 9+1 dimensional.
All Matter & Forces in the Universe Unified by String Theory
Particles & Forces
Like Notes on a Violin String
The 6 extra dimensions of String Theory were said to be "compact"—very small and closed, i.e. circular-like and very small ~ $10^{-33}$ cm in length (minute even in comparison to even the nuclear scale of $10^{-13}$ cm). That is, the Whole Story of the Universe was shown to be much more complex than realized prior, but nevertheless the enlargement of 3 spatial dimensions into 9 spatial was still consistent with the Univercentric Paradigm.
9 Dim $\otimes$ 3 Large Dim
+ 6 Compact Dim

Products of 6 Circular Directions

Forming

Spherical or Toroidal

Too Simple!
The particles and forces in nature were found to require a Calabi-Yau shape formed by the 6 Compact Dimensions.
Can extra dimensions help with dark energy? Maybe.

Crucial fact: there's not just one good way to compactify, there are many.

Around $10^{12}$ compactifications!

The “constants of nature” we observe depend on the shape and size of the compact manifold. Everything changes from one compactification to the next, including the value of the vacuum energy.
Finite Initial Size and Temperature of String Theory Universe

T - Duality

\[ T(1/R) \leftrightarrow T(R) \]

\[ \ln R \leftrightarrow -\ln R \]

No initial singularity

SBB

BGC

Winding modes

\[ T \]

\[ \ln R \]

\[ 0 \]
Soon after the “First String Revolution” in 1984, which provide mathematical proof of String Theory as a consistent 10-dimensional quantum theory, String Theory was proffered as a Theory of Everything. However, in truth it was actually 5 Theories of Everything. 5 different, apparently unique String Theories (Type I, Type IIA, Type IIB, Heterotic E8\(\otimes\) E8, and Heterotic SO(32)), were found, each of which predicted slightly different fundamental string-like particles.
Nagging Problem for 1st Decade (1985-95): Not Just 1 10-Dimensional String Theory But 5!

www.sukidog.com/jpierre/strings/
The “Second String Revolution” of 1994-95 resolved this pivotal issue by showing that all five apparently distinct theories were, in fact, equivalent—that they were different mathematical expressions of the same underlying theory.
Solution: Duality (Equality) of All 5 String Theories

www.sukidog.com/jpierre/strings/
Each ‘Theory’ is SAME THEORY IN DIFFERENT MATHEMATICAL LANGUAGE

www.sukidog.com/jpierre/strings/
However, in the underlying theory the fundamental particle was shown to no longer be just string-like, but that it gained an additional spatial dimension to become membrane-like.
- String w/ 10 Dim → Membrane w/ 11 Dim

[Diagram showing the transition from a string to a membrane, with the addition of a 11th dimension for the membrane.]
And with the appearance of an additional spatial dimension, quantum mechanical consistency required that the dimension of spacetime also increase by one to $10+1$ as well.

Thus, String Theory was subsumed by M Theory.

The simplest M theory model contain two 9-dimensional surfaces (9-branes) separated by the new spatial direction—one of which contains our universe. More complicated models can contain more 9-dimensional surfaces moving between the 2 fixed branes.
Two 9-brane “Universes” = “Us & Them” and an extra dimension between
Dark Matter keeps arms of spiral galaxies stable & also keeps Galactic clusters stable. In string theory, dark matter is the matter in the hidden universe and is shifted away by a short distance along the new extra direction.
Compactify 6 of the 9 Spatial Directions of each Brane as Before

Motivations from String Theory/M-theory

10+1 dimensions
compactify 6 dim. on C-Y manifold

P. Horava & E. Witten
A. Lukas, B. Ovrut and D. Waldram
Effective 5-Dimensional Theory

Motivations from String Theory/M-theory

- 10+1 dimensions
- Compactify 6 dim. on C-Y manifold
- Effective 5d theory

heterotic M-theory
Size of 5th Dimension?

$10^{-33} \text{ cm} < \Delta y < 0.1 \text{ mm}$

Horava et al.
Tests for sub-\text{mm}. directions

\[ F_{\text{grav}} = \frac{-Gm_1m_2}{r^2} \rightarrow \frac{-Gm_1m_2}{r^{2+n}} \]

If gravity leaks into extra dimensions, Newton's inverse-square law should break down at small distances - gravity will be stronger than you think.

Standard gravity verified down to 0.15 mm at Univ. of Wash. with 97\% confidence level.
Manufacturing of Stringy Blackholes!

- If sub-mm. dimension then it may be possible to produce gravitons and mini-black holes (with pico-second half-lives) at Fermilab & CERN this decade!

- Mini-black holes have distinct decays — easily identifiable!

- Black Holes Detectors for Fermilab and CERN
Proposed Explanation for Big Bang

Implying Time Before Time!

Making an Ekpyrotic Universe

1. A membrane with strange physics bounds one end of the fifth dimension.

2. A membrane destined to become our universe bounds the other end.

3. Other membranes move within the fifth dimension.

4. When one slams into "our" membrane, the universe we now live in is born.

ROBERT ROY BRITT / SPACE.COM
The Big Crash: Ekpyrotic model

Eons before the Big Bang

Big Bang (15 billion years ago)

Today

Galaxies form and the universe evolves, once and only once.

Flat, parallel branes collide and stick to create the universe.

Due to the finite separation between them, the branes could collide over and over in cycles of creation and destruction.

Flat, parallel branes collide and bounce. Our universe evolves on one of the branes, while the other remains hidden.
The colliding Branes would not remain perfectly flat as they approach each other due to quantum effects. 

Big Bang Inflations occurs in bumps on Branes that collide first.

Multiple (vast number of), separated, Big Bang regions would likely have been formed from distinct collision points of Branes! 

→ Multiple universes on our Brane besides 1+ Parallel Branes along an extra spatial direction
String Landscape

\[ \sim 10^{12} \times 10^{100} \text{ to } 1000 \text{ Models in M-Theory} \]

new factor is M-theory effect

C.C./dark energy

\[ (10^{18} \text{ GeV})^4 \]

\[ (10^{-12} \text{ eV})^4 \]
Excited modes with energy gaps of no more than $10^{-120}\,\text{M}_{\text{Pl}}^4$.

Our universe:

At least $10^{500}$ possible String Model Universes.

Vacuum near $-1$.
M Theory implies the existence of a Multiverse that contains at least $10^{100}$ to $10^{1000}$ (often “averaged” in discussions to $10^{500}$) universes within. Each universe is brought about by its own Big Bang/Inflation Process and may contain vastly differing physical laws. The near-countless possibilities for universes is known as the string/M landscape. A significant percent of these universes may provide for something similar to carbon-based life forms; others may provide for vastly different life forms. And the vast majority may not allow for any life forms whatsoever.
In the Multiverse of M Theory vast numbers of universes are likely created “simultaneously.” Creation of universes within the M Theory Multiverse may also be unending, with creation cycles of new universes predicted by the Ekpyrotic M theory models to be on the same time scale as that in which old universes wear out—hundreds of billions to trillions of years.
Multiverse of String Cosmology

- Next step in our perception of reality? Now undergoing this Paradigm shift.

- Provides much deeper understanding of the whole story of creation, with a simplicity, order, and beauty and complexity to creation never before imagined.