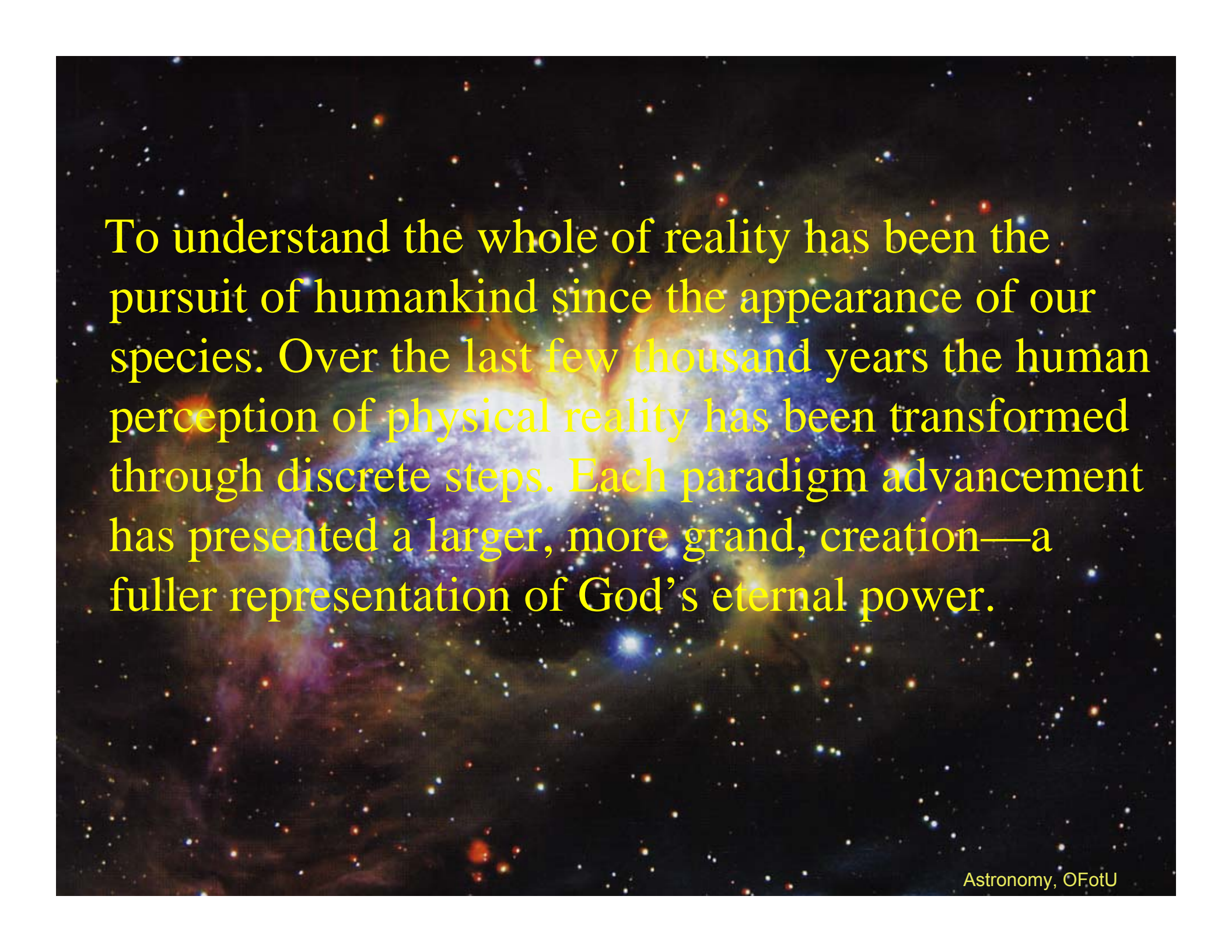


The Multiverse —Next Step in Our Growing Understanding of Reality?

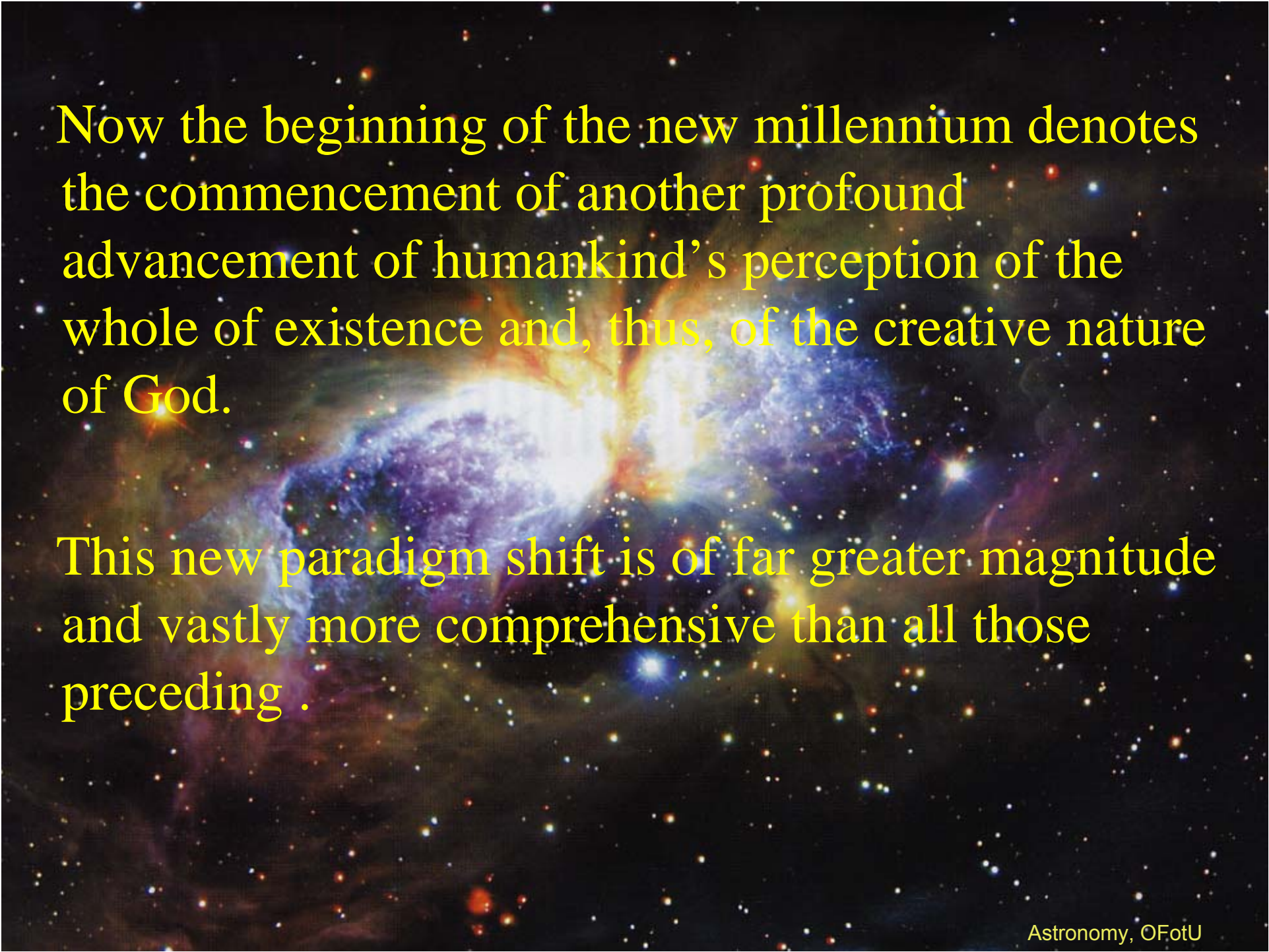
Gerald B. Cleaver

Baylor University
PHYSICS



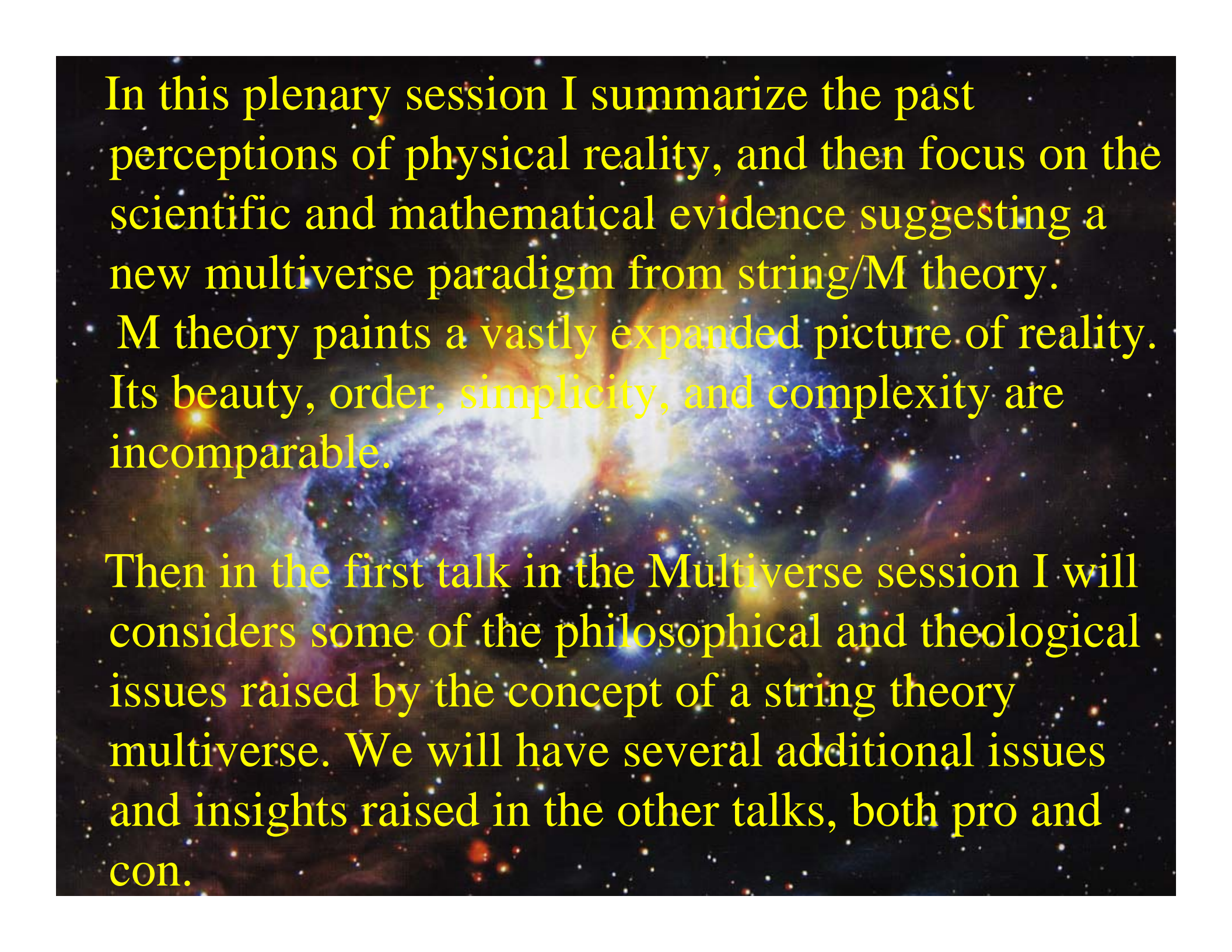


To understand the whole of reality has been the pursuit of humankind since the appearance of our species. Over the last few thousand years the human perception of physical reality has been transformed through discrete steps. Each paradigm advancement has presented a larger, more grand, creation—a fuller 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.

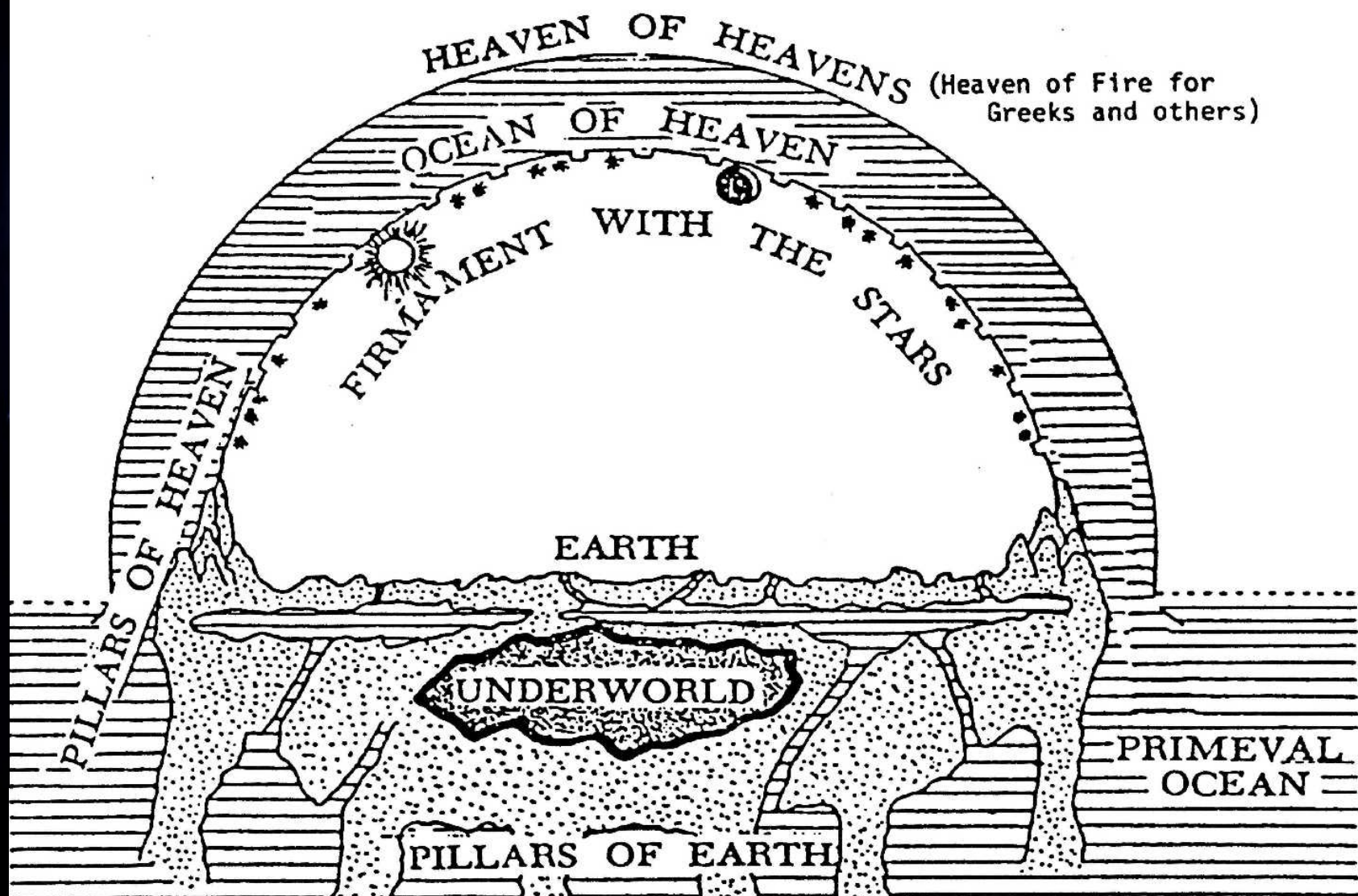
This new paradigm shift is of far greater magnitude and vastly more comprehensive than all those preceding .



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.

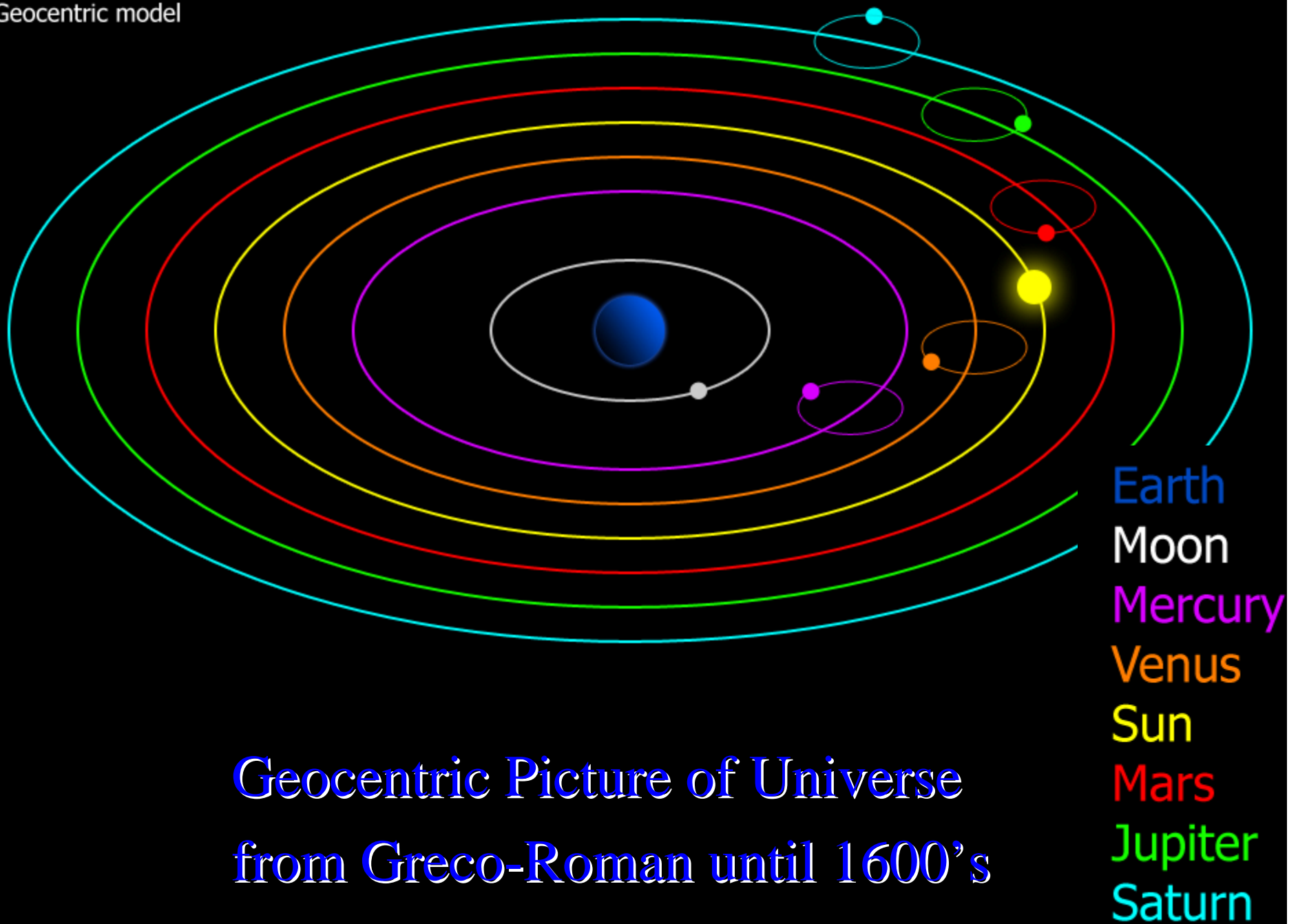
M theory paints a vastly expanded picture of reality. Its beauty, order, simplicity, and complexity are incomparable.

Then in the first talk in the Multiverse session I will consider 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.



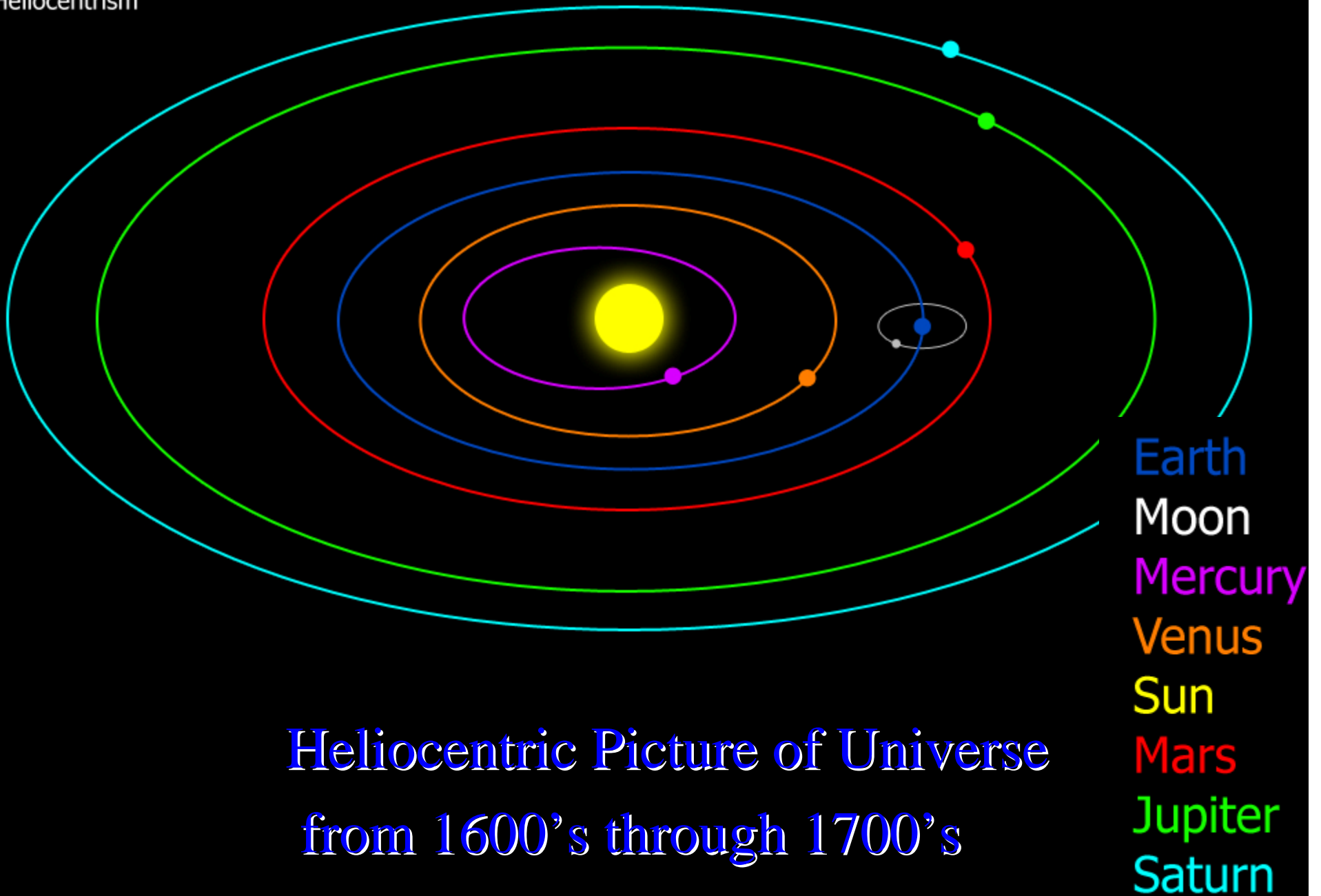
3 Story Universe
of the ancient Mideast world

Geocentric model



Geocentric Picture of Universe
from Greco-Roman until 1600's

Heliocentrism



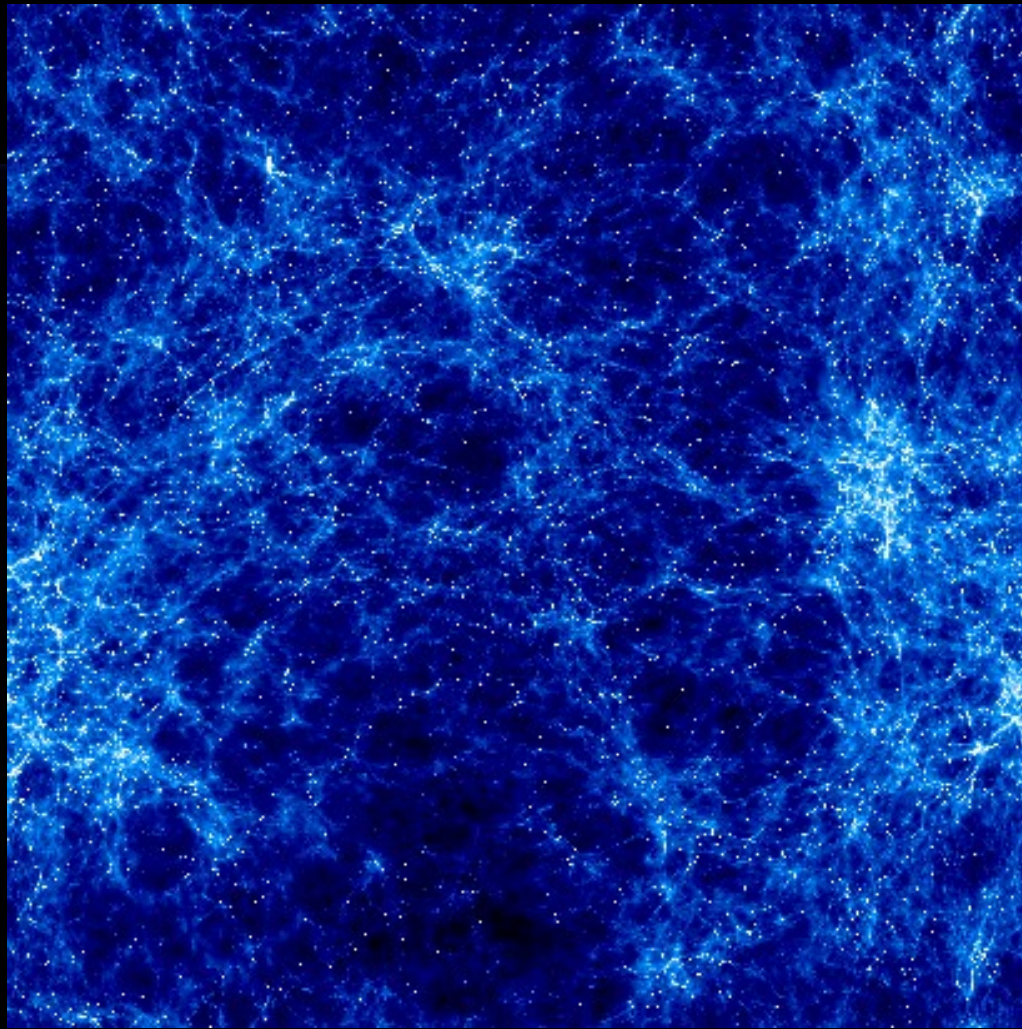
Heliocentric Picture of Universe
from 1600's through 1700's



Galactocentric 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.



(Each dot
of light
is an
entire
galaxy)

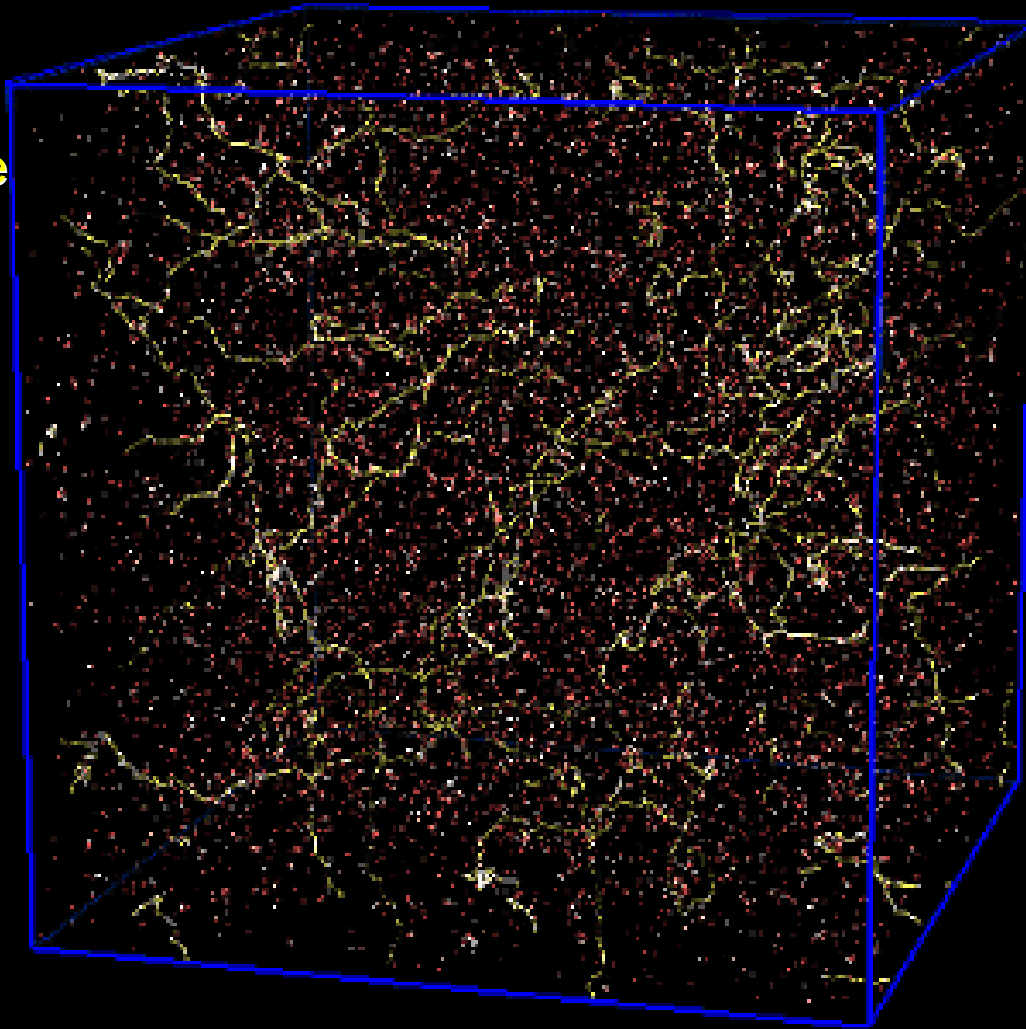
**Univercentric Picture of Universe
from 1900's (until 2000's?)**

Visible Universe

Visible Universe
is 13.7 billion
light years
in diameter

= 8×10^{22} mi

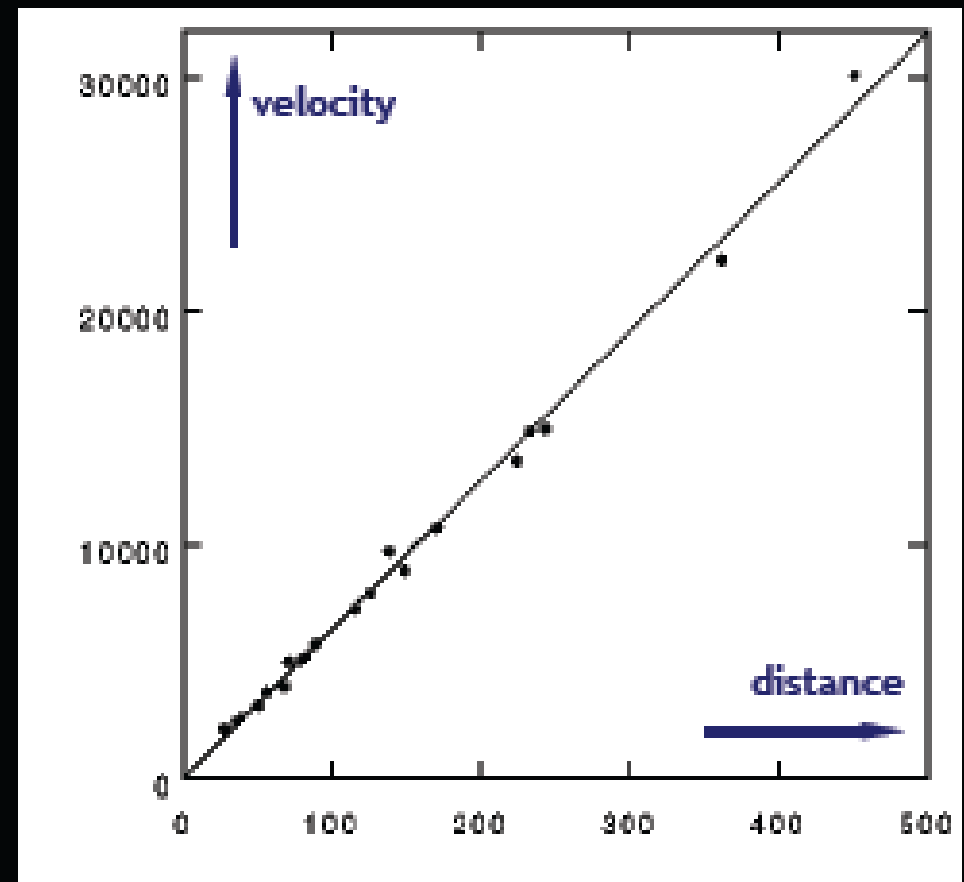
Current size is
over twice this.



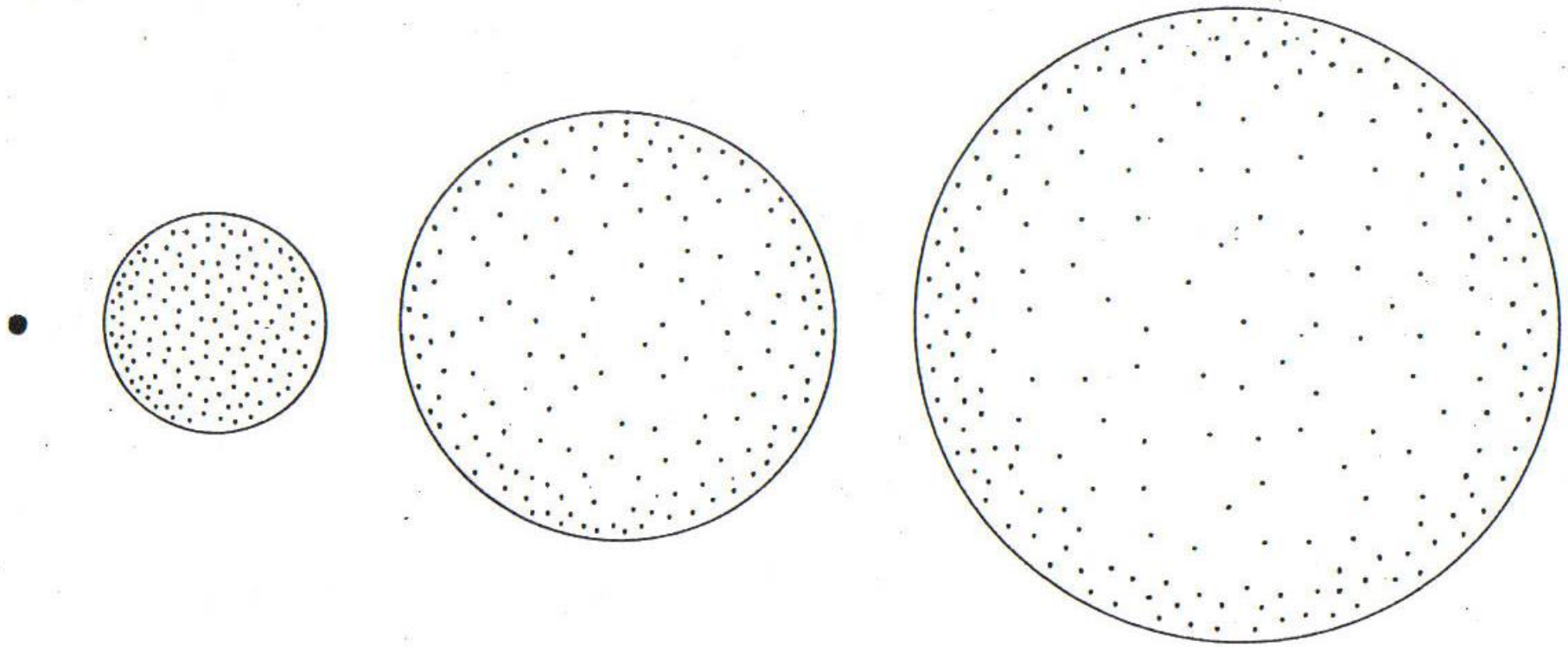
trillion galaxies,
trillion stars per
galaxy

What is more: the universe is expanding.

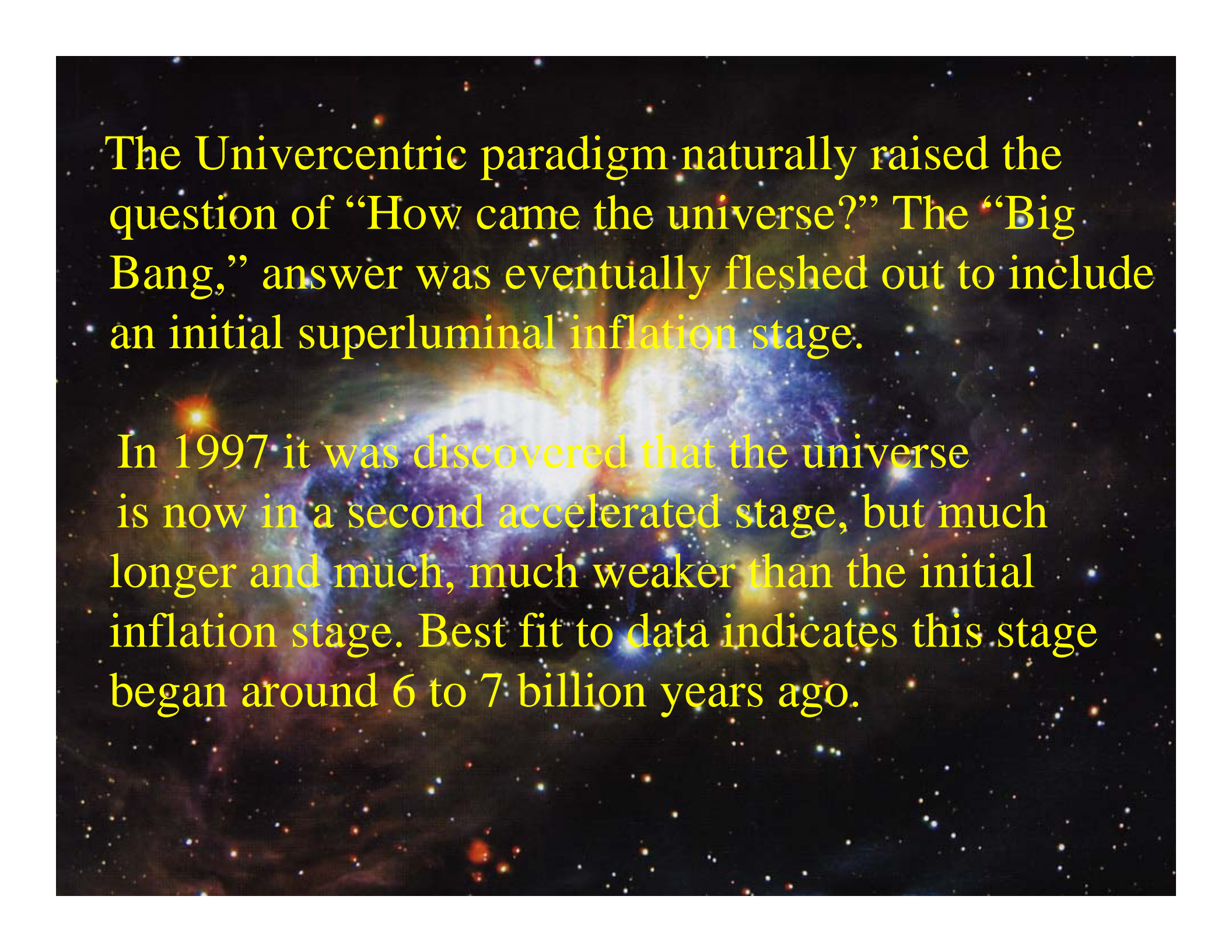
1929: Hubble again, this time showing that the further away a galaxy is, the more rapidly it is moving away from us.



Modern version of Hubble's diagram.



- 2 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 background of the slide is a deep space image. It features a central, bright, multi-colored galaxy core with hues of yellow, orange, and blue, surrounded by a dense field of distant stars and nebulae in various colors like red, blue, and purple.

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.

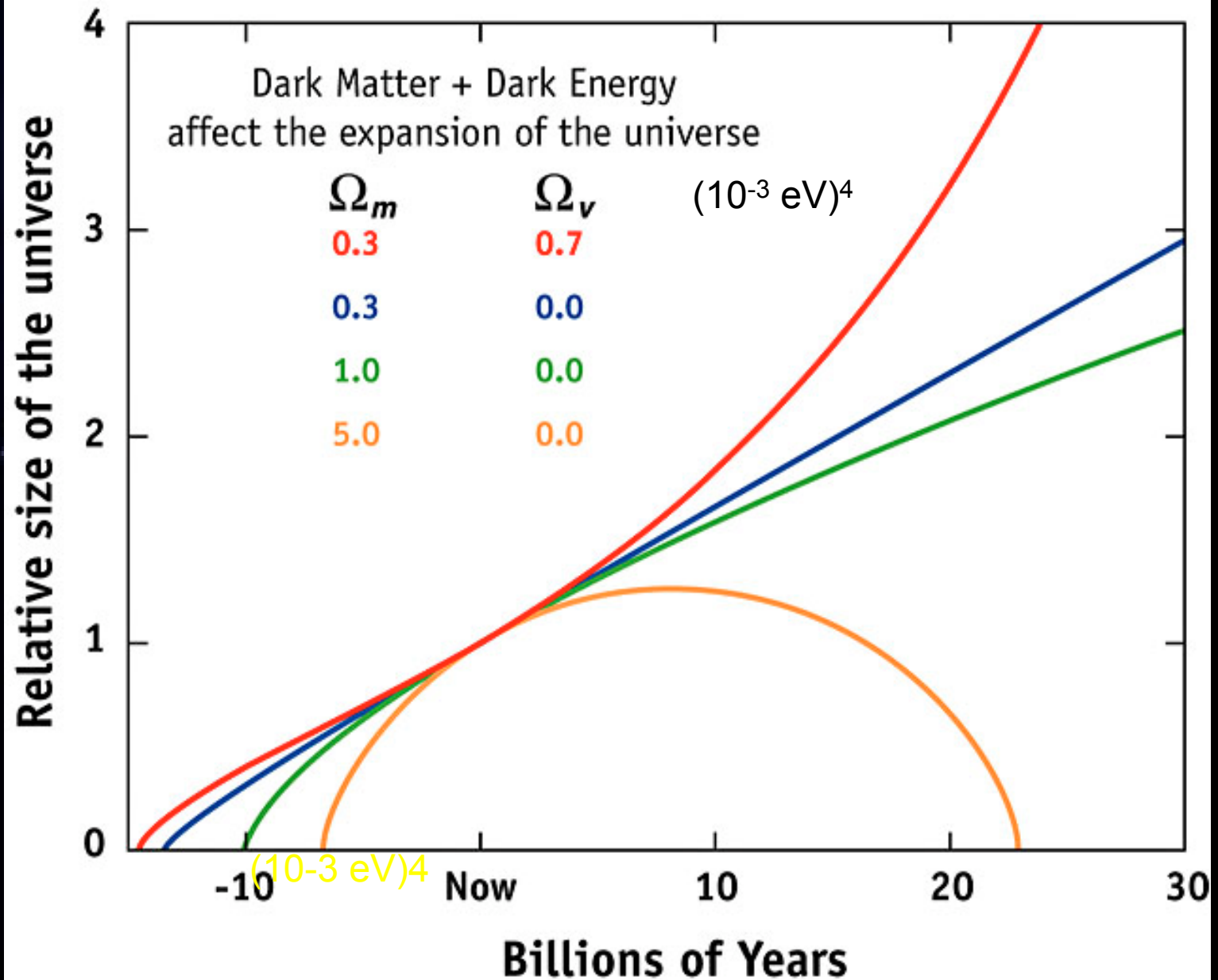
In 1997 it was discovered that the universe is now in a second accelerated stage, but much longer and much, much weaker than the initial inflation stage. Best fit to data indicates this stage began around 6 to 7 billion years ago.

What would make the universe accelerate?

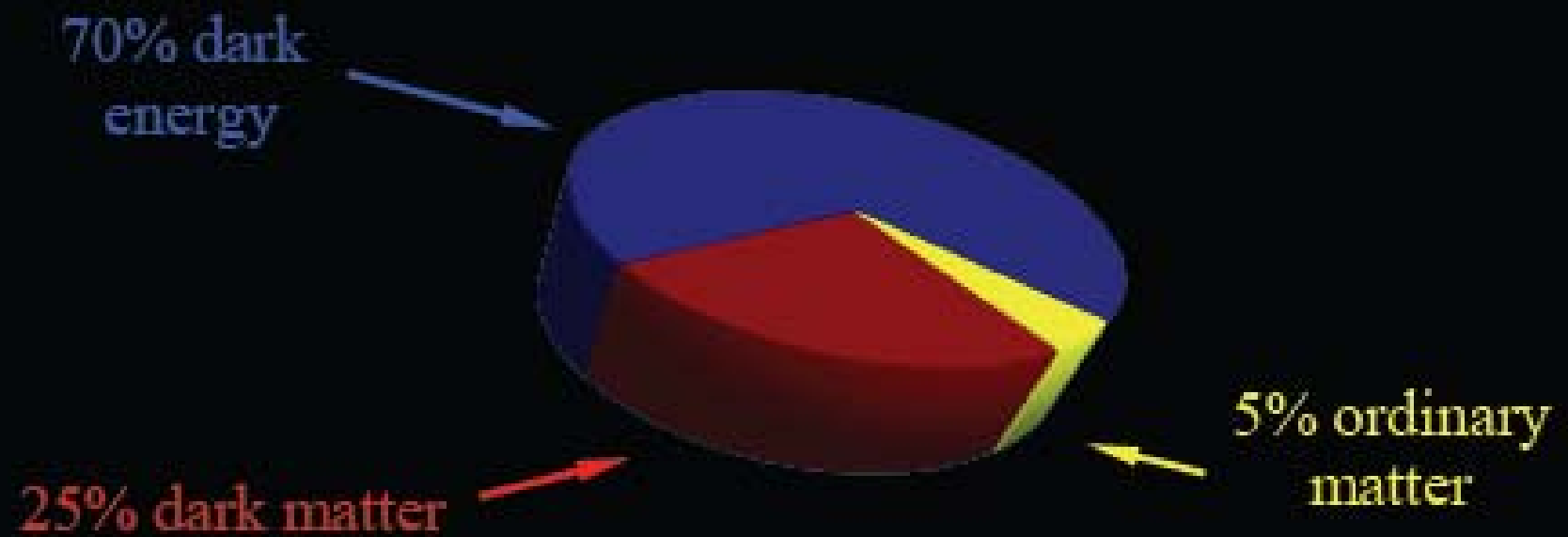
Best answer: **Dark Energy**. A form of energy that exists even in empty space (“vacuum energy”).

- **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.

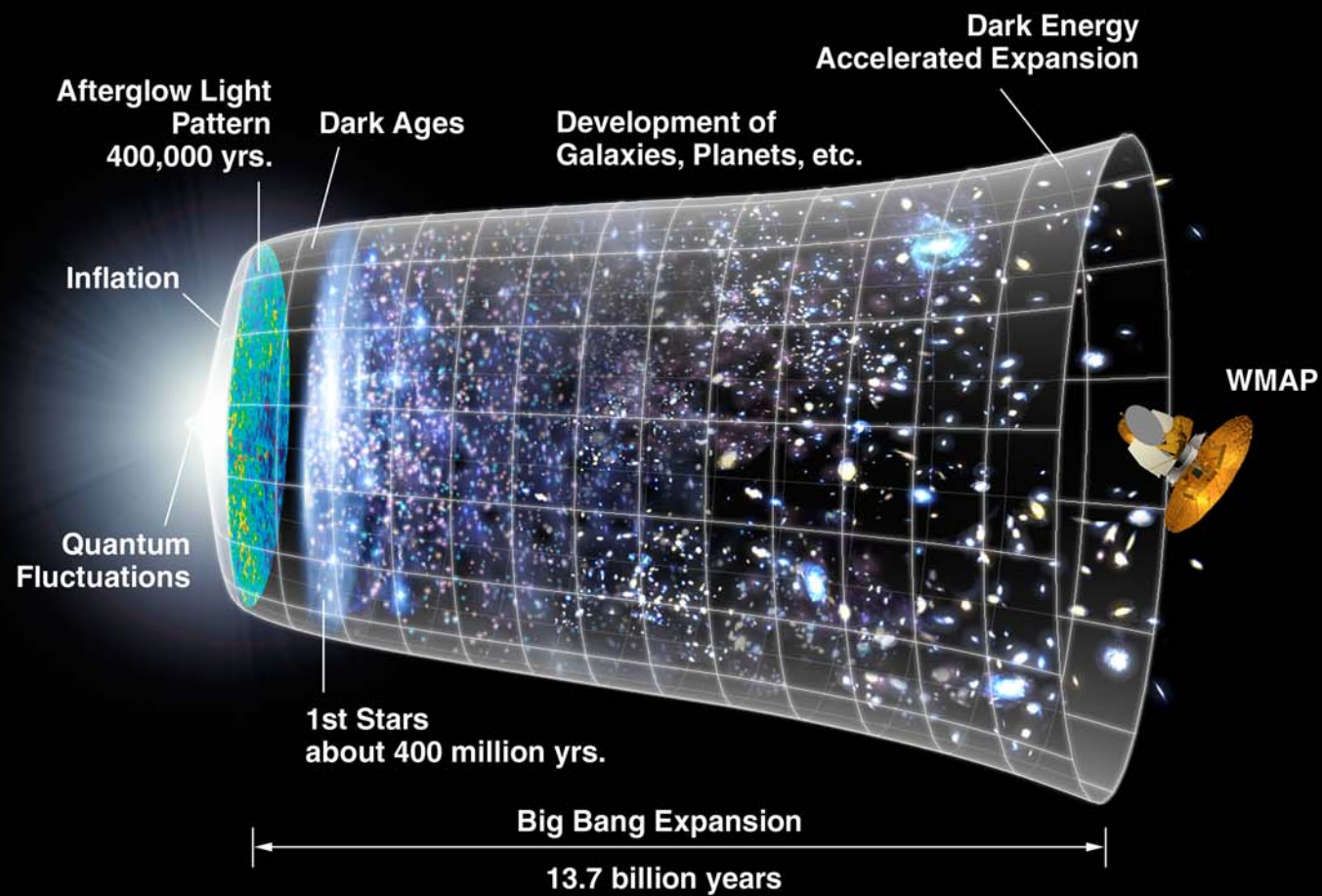
EXPANSION OF THE UNIVERSE

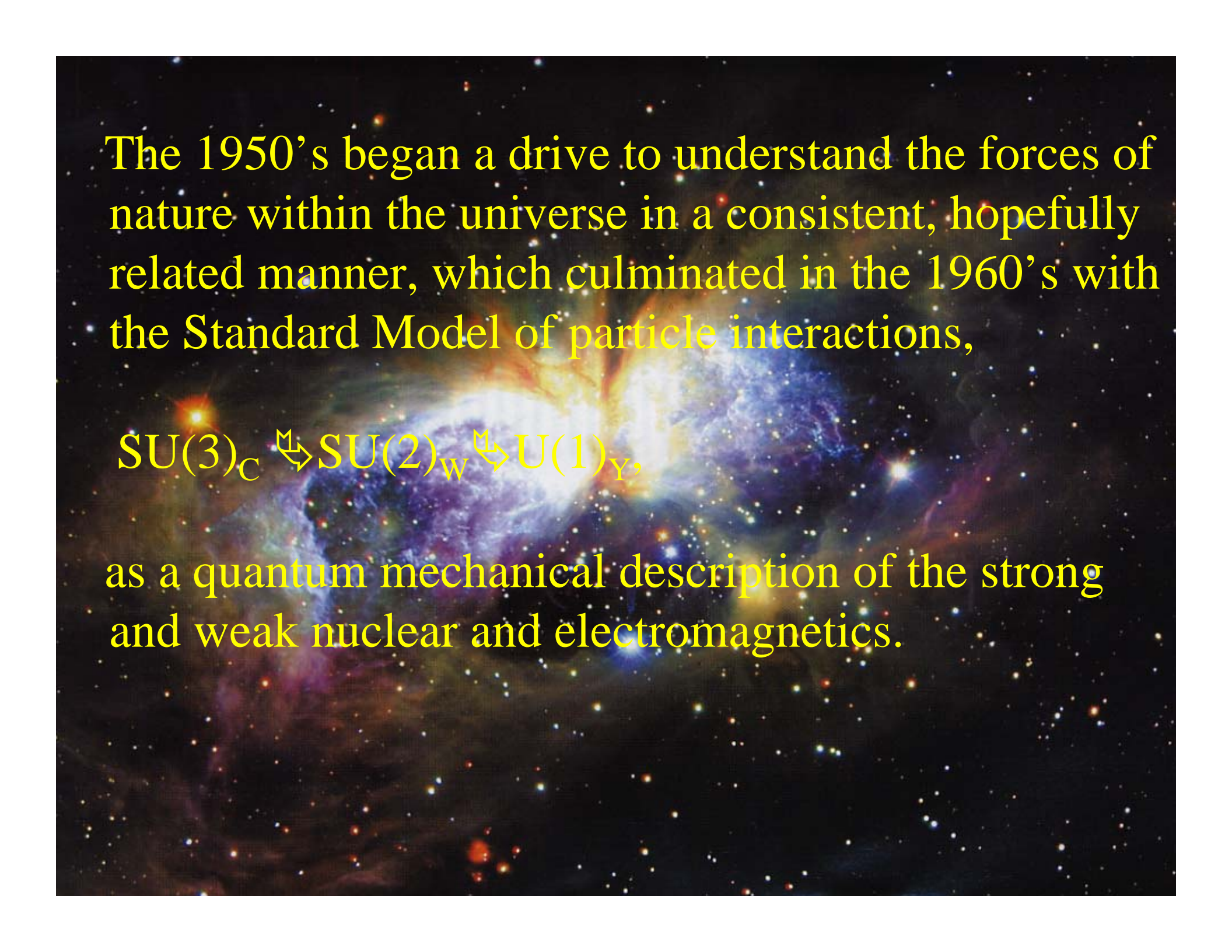


We therefore seem to have a **complete inventory** of the stuff of which the universe is made:



Seeking simplicity, we are led to astonishing ideas.
What will be next?

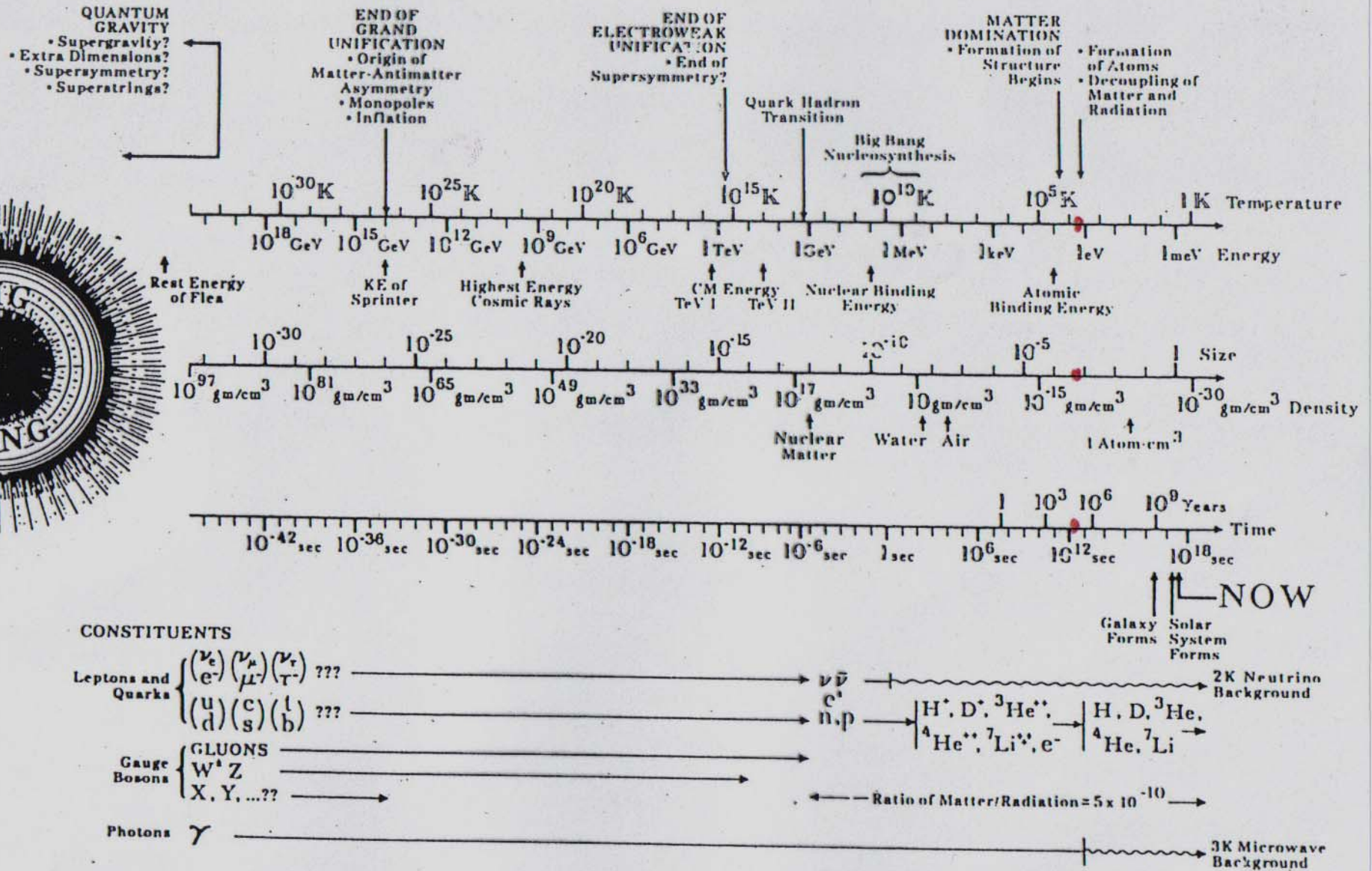
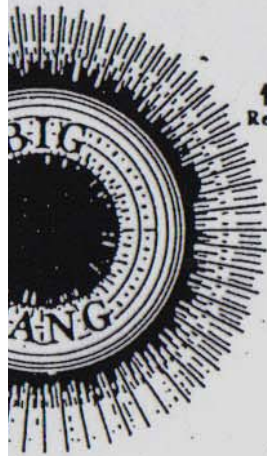




The 1950's began a drive to understand the forces of nature within the universe in a consistent, hopefully related manner, which culminated in the 1960's with the Standard Model of particle interactions,

$$SU(3)_C \xrightarrow{M} SU(2)_W \xrightarrow{M} U(1)_Y,$$

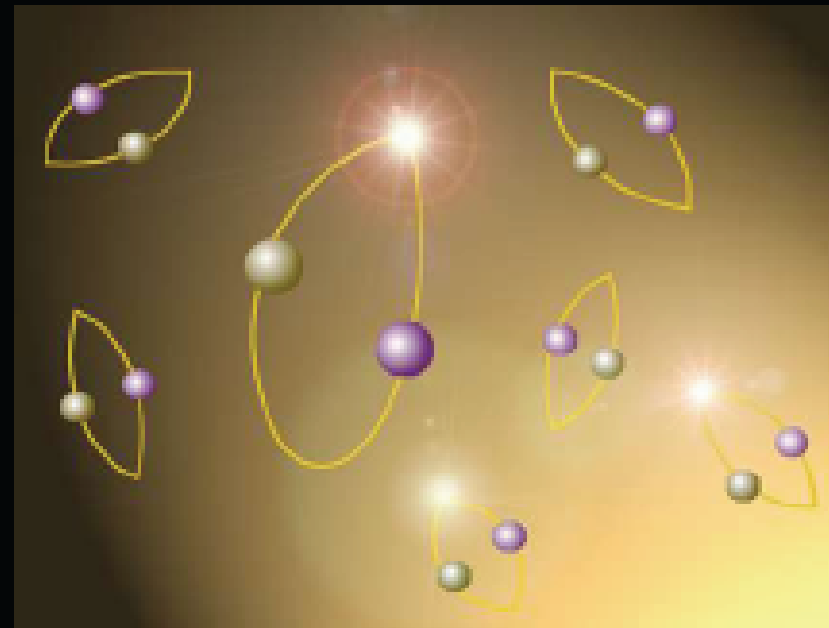
as a quantum mechanical description of the strong and weak nuclear and electromagnetics.



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).



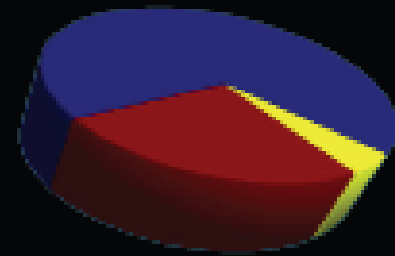
A quick back-of-the-envelope calculation reveals:

theoretical prediction = 10^{120} times observation.

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

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?

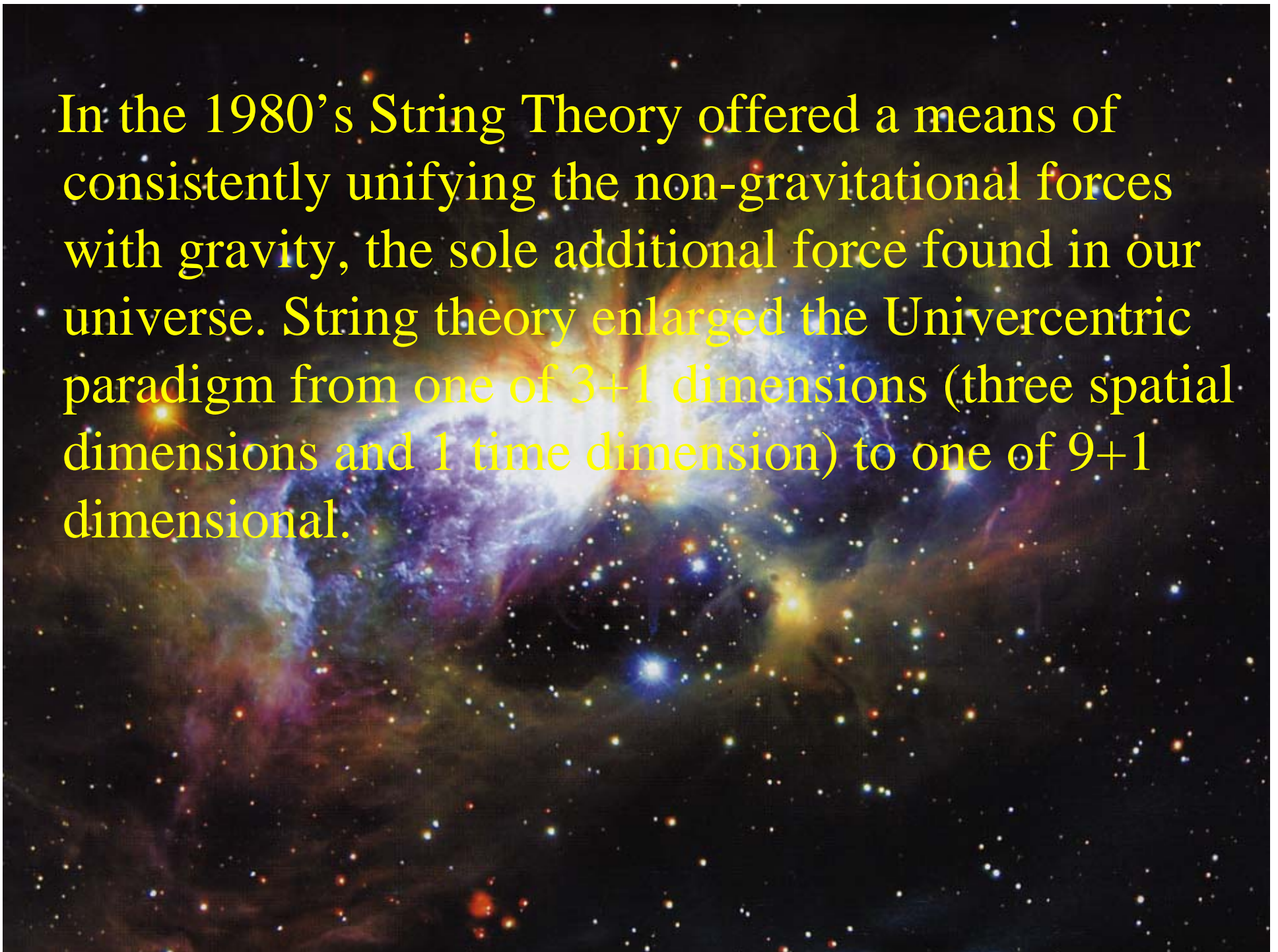
Look for big ideas to tie things together.

Physicists seeking

the Theory of Everything (Physical)

*Scientific Understanding of the Universe
Sought in String/M Theory*

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

A[♭]



D



E[♭]



B



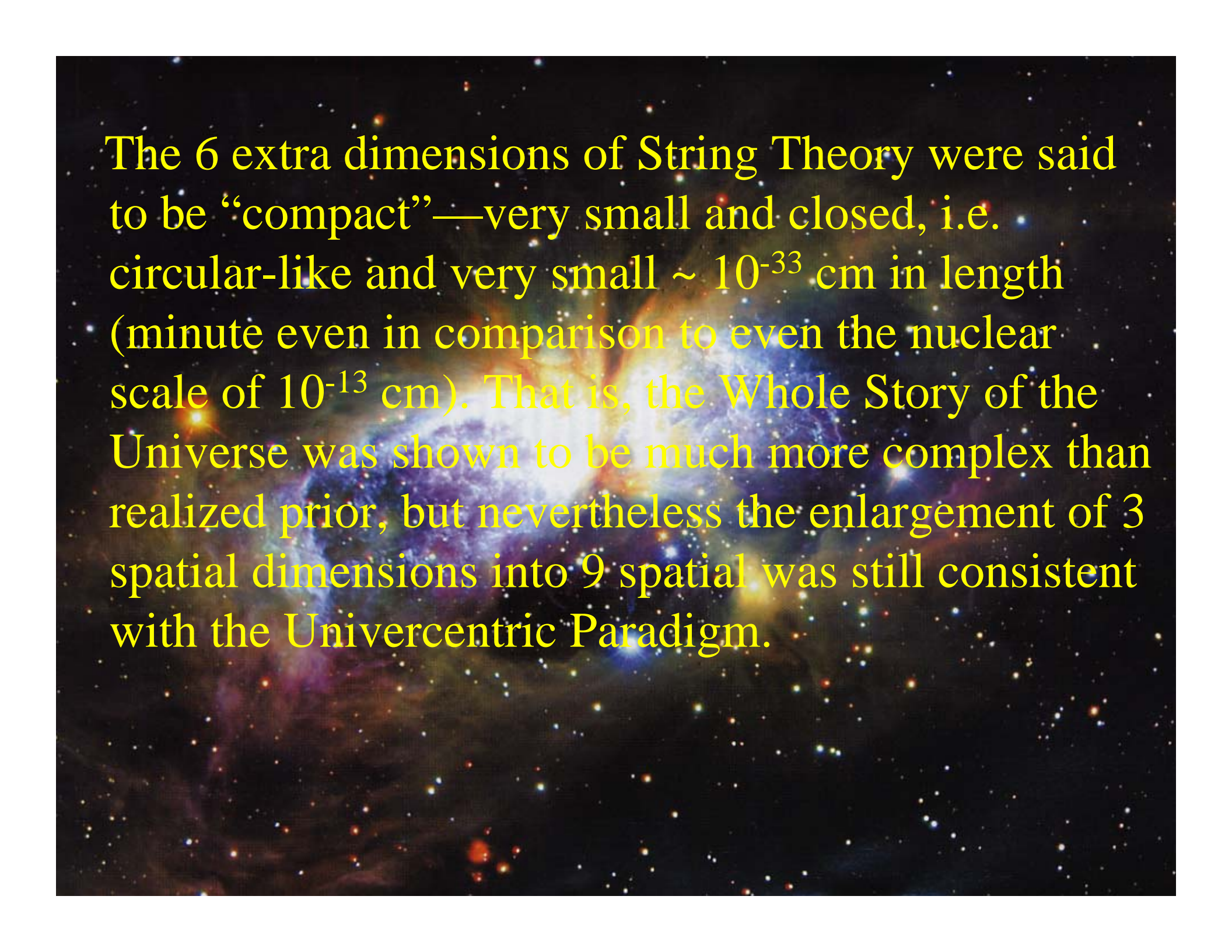
C[♯]



G[♯]

F[♯]

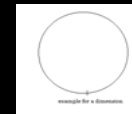
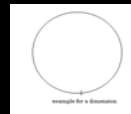
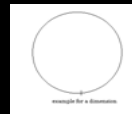
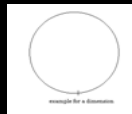
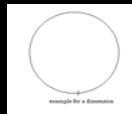
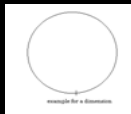




The 6 extra dimensions of String Theory were said to be “compact”—very small and closed, i.e. circular-like and very small $\sim 10^{-33}$ cm in length (minute even in comparison to even the nuclear scale of 10^{-13} cm). That is, the Whole Story of the Universe was shown to be much more complex than realized prior, but nevertheless the enlargement of 3 spatial dimensions into 9 spatial was still consistent with the Univercentric Paradigm.

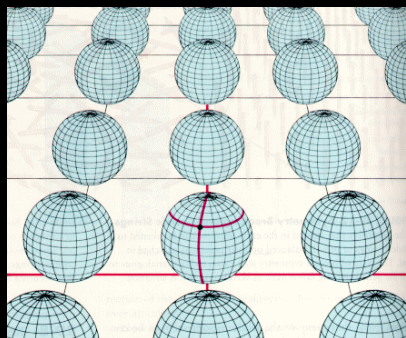
9 Dim ⑨ 3 Large Dim
+ 6 Compact Dim

Products of 6 Circular Directions



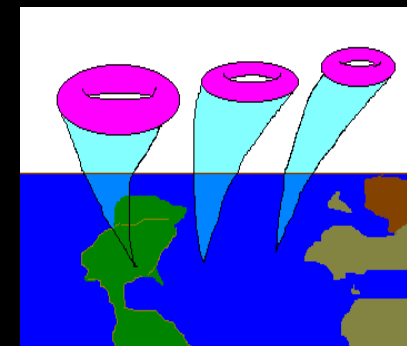
Forming

Spherical



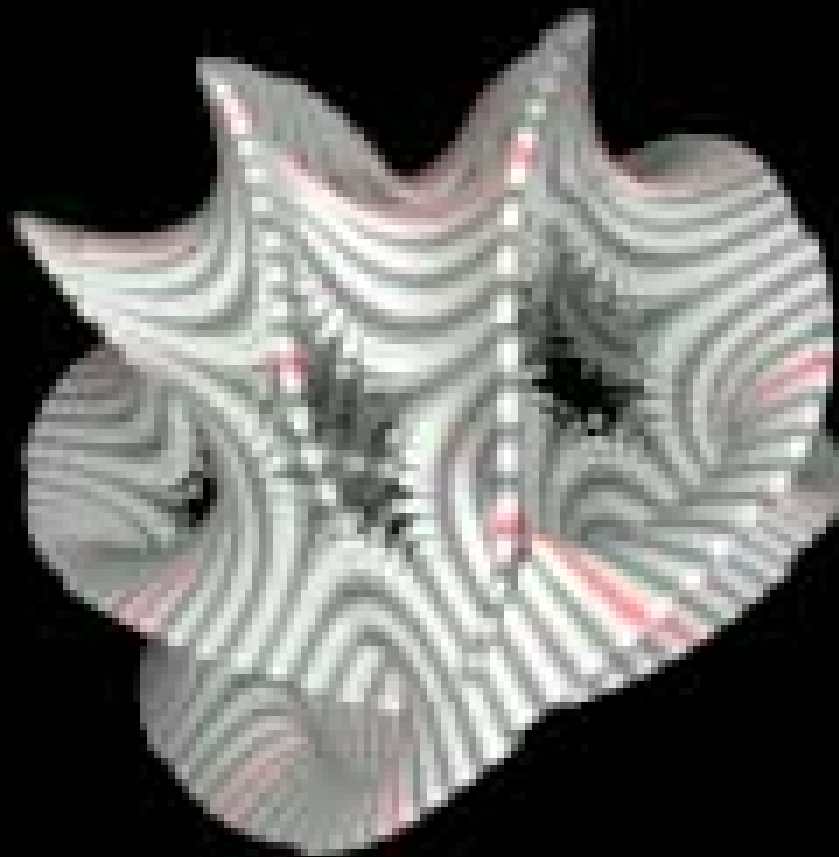
or

Toroidal



Too Simple!

The particles and forces in nature were found to require a Calabi-Yau shape formed by the 6 Compact Dimensions



2 Dim Surface C-Y Surface—Need to extend to 6 Dim

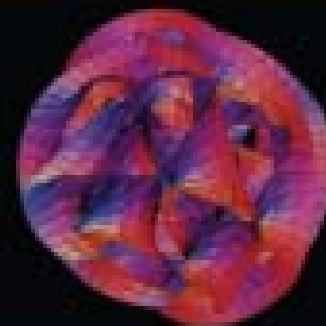
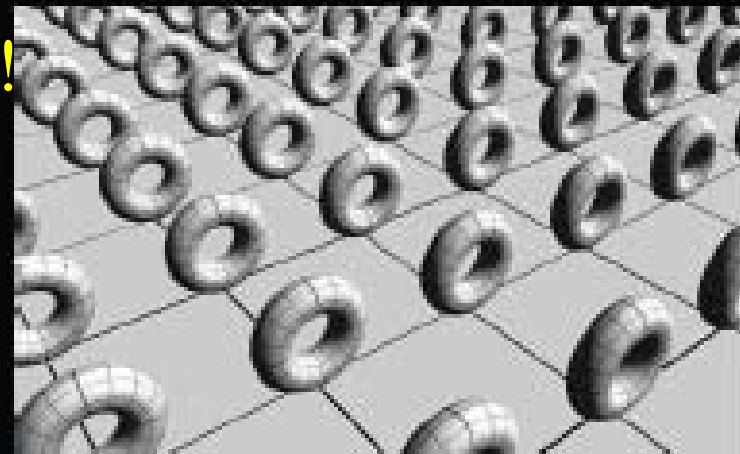
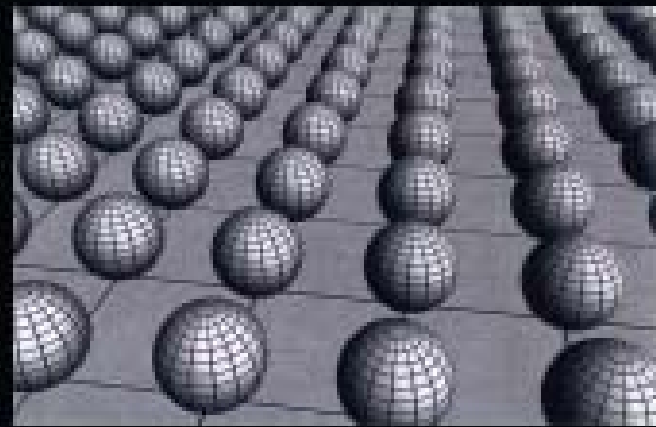
Can extra dimensions help
with dark energy? Maybe.

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.



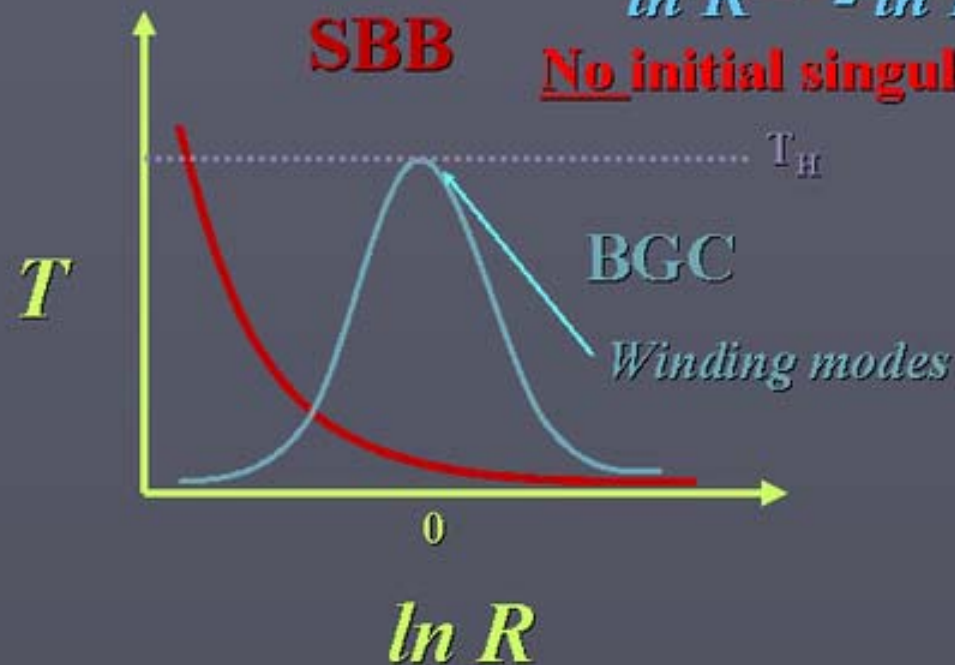
Finite Initial Size and Temperature of String Theory Universe

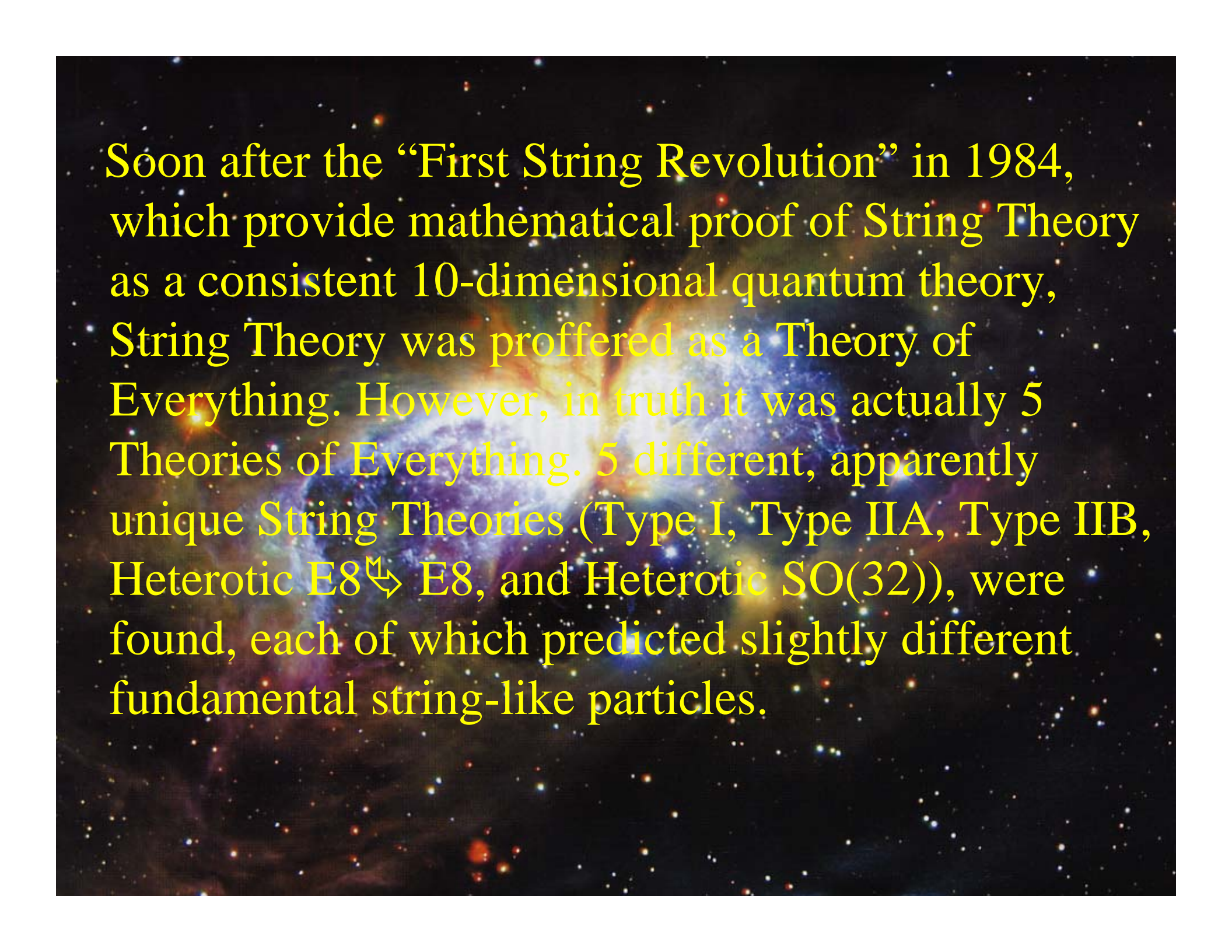
T - Duality

$$T(1/R) \leftrightarrow T(R)$$

$$\ln R \rightarrow -\ln R$$

No initial singularity



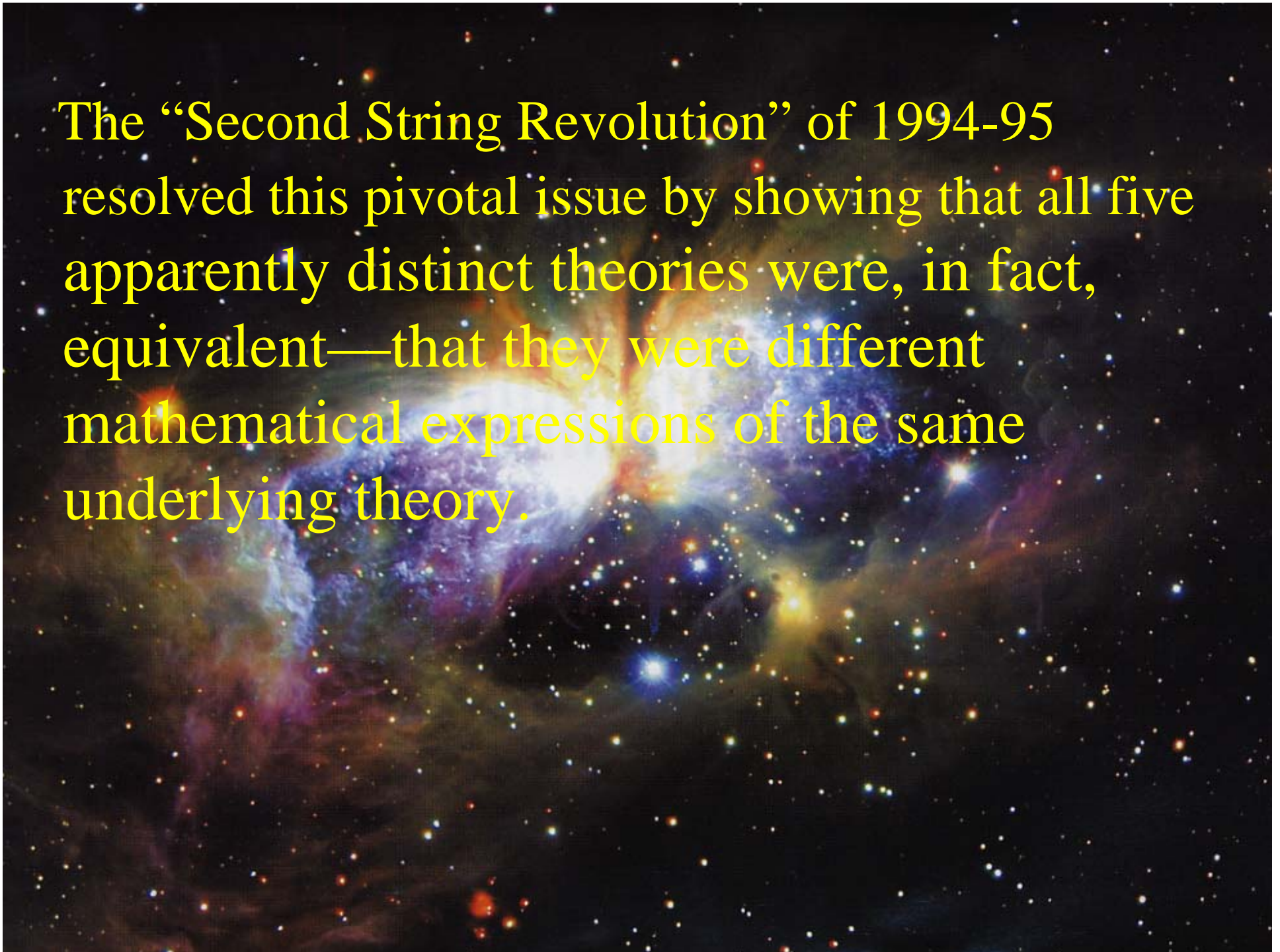
The background of the slide is a deep space image featuring a vibrant, multi-colored nebula in the center, with hues of blue, purple, and orange. The surrounding space is dark, filled with numerous small, distant stars and some faint, wispy clouds of interstellar dust.

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 $E_8 \hookrightarrow E_8$, and Heterotic $SO(32)$), were found, each of which predicted slightly different fundamental string-like particles.

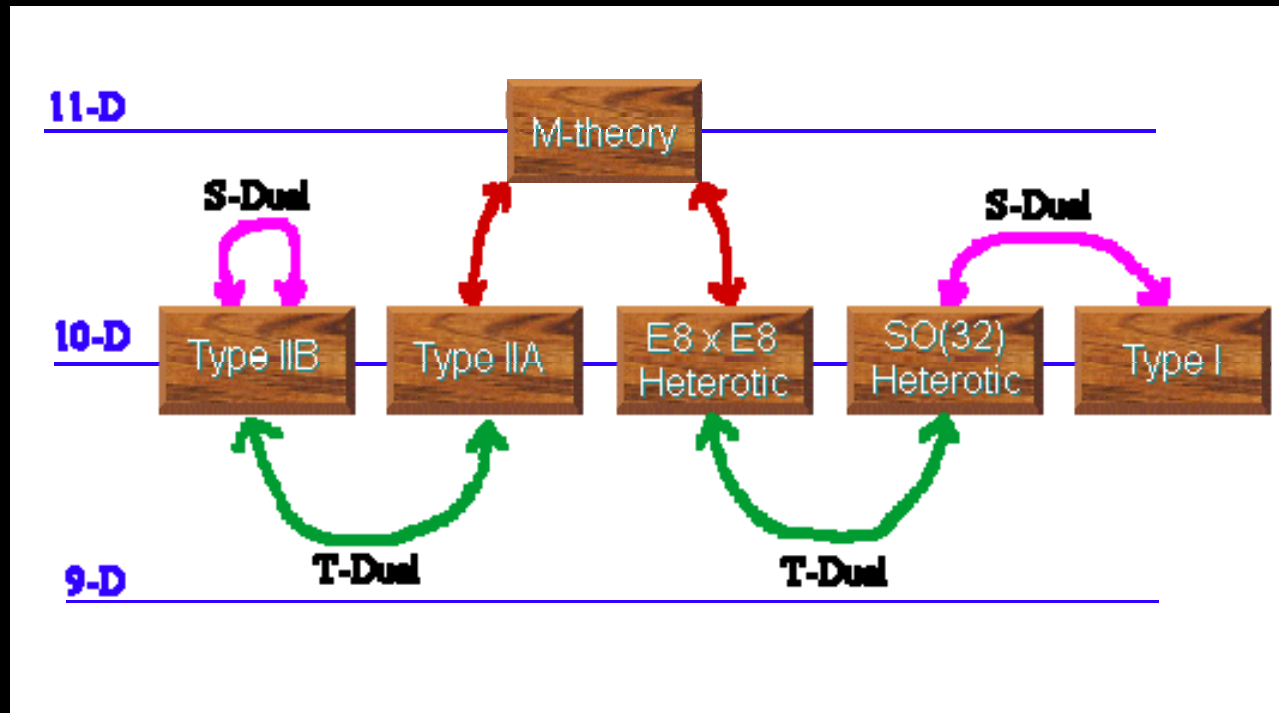
Nagging Problem for 1st Decade (1985-95): Not Just 1 10-Dimensional String Theory But 5!



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.



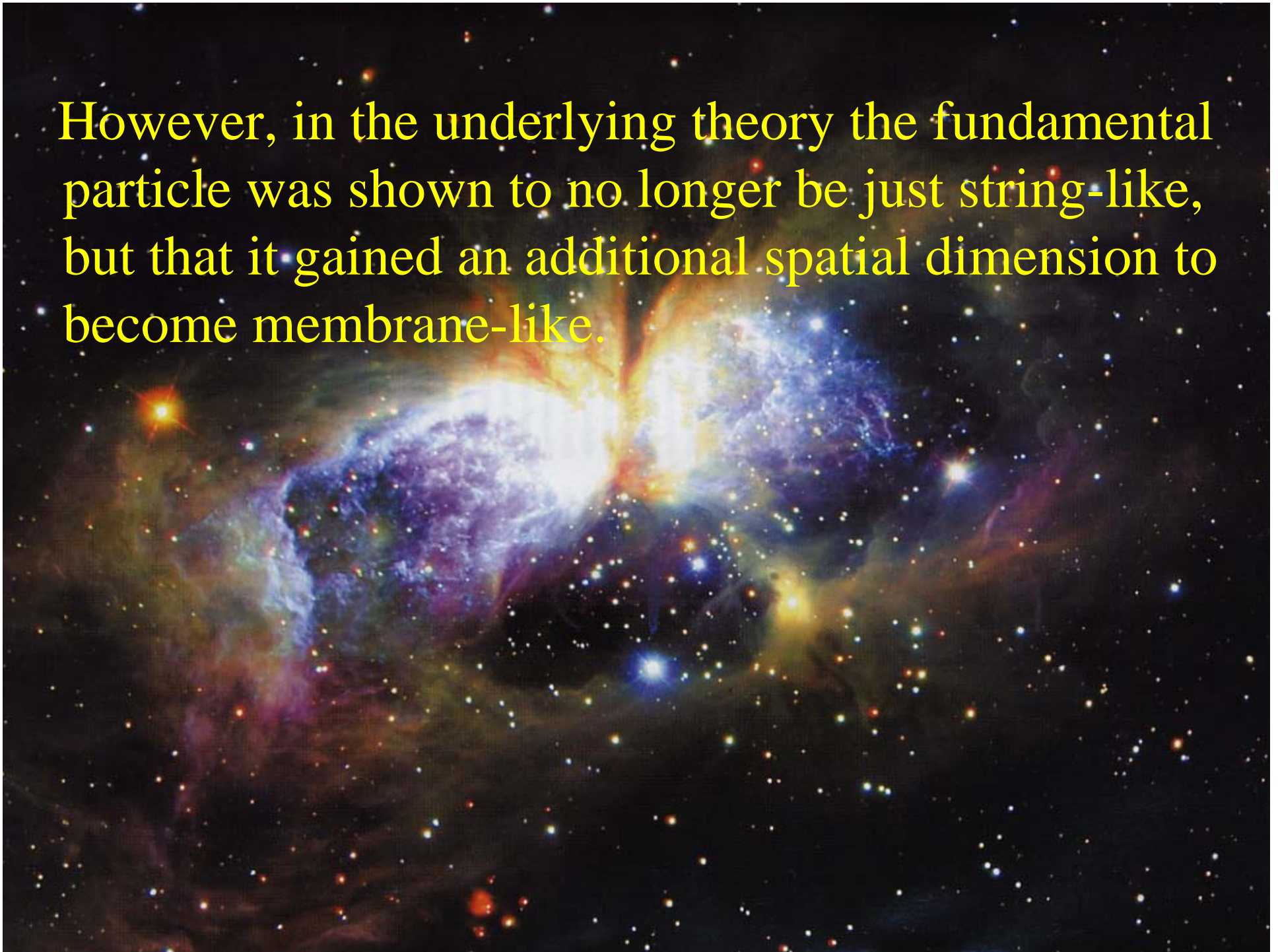
Solution: Duality (Equality) of All 5 String Theories



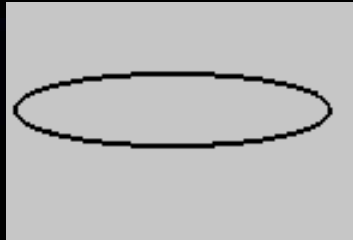
Each ‘Theory’ is SAME THEORY
IN DIFFERENT
MATHEMATICAL LANGUAGE



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.

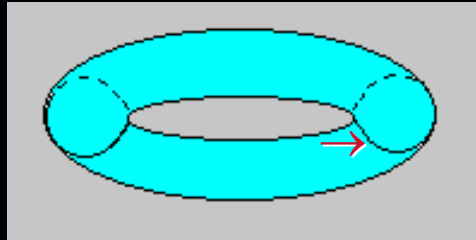


String

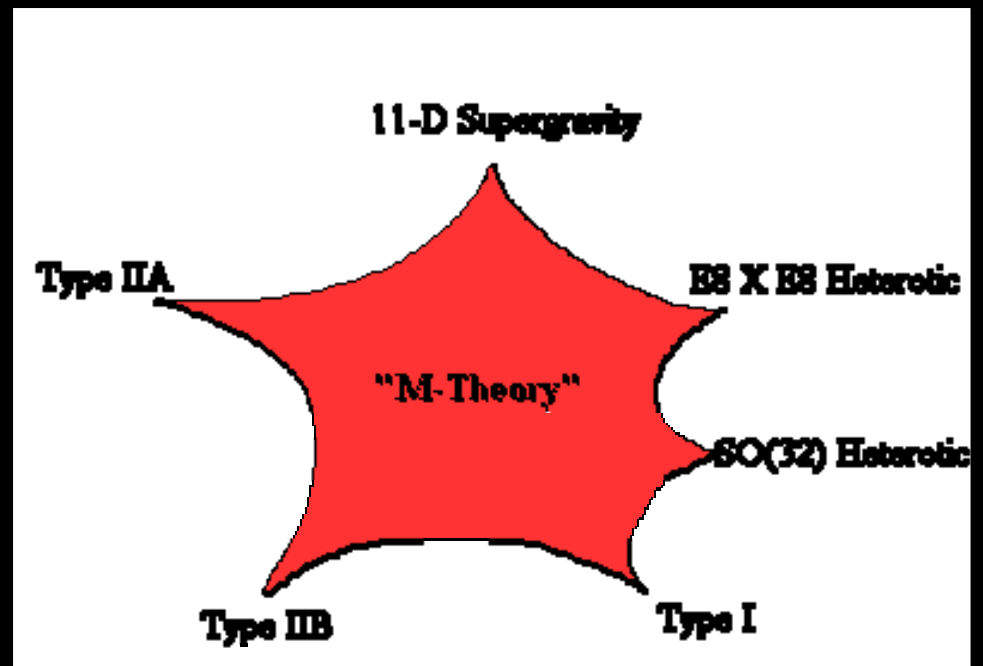


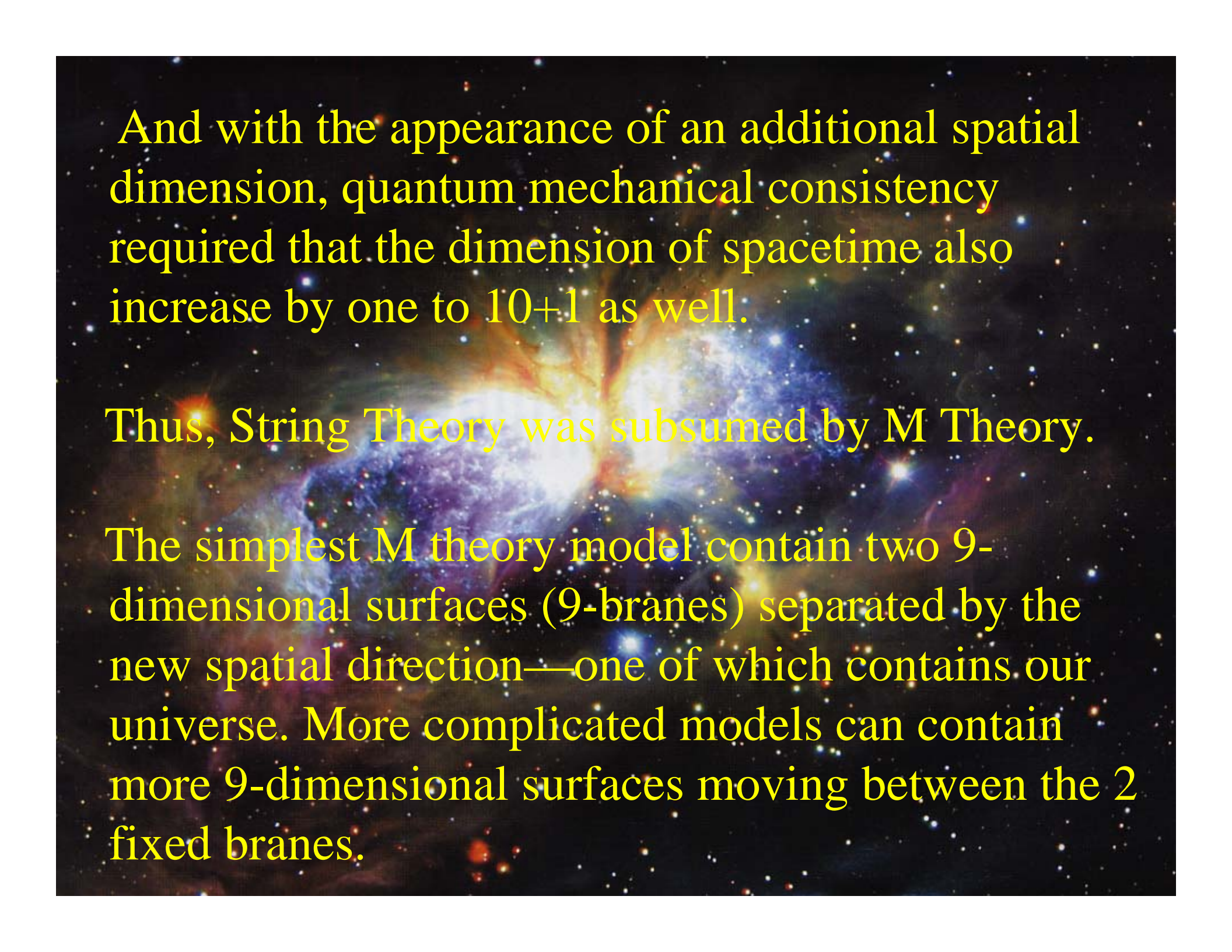
w/ 10 Dim

Membrane



w/ 11 Dim



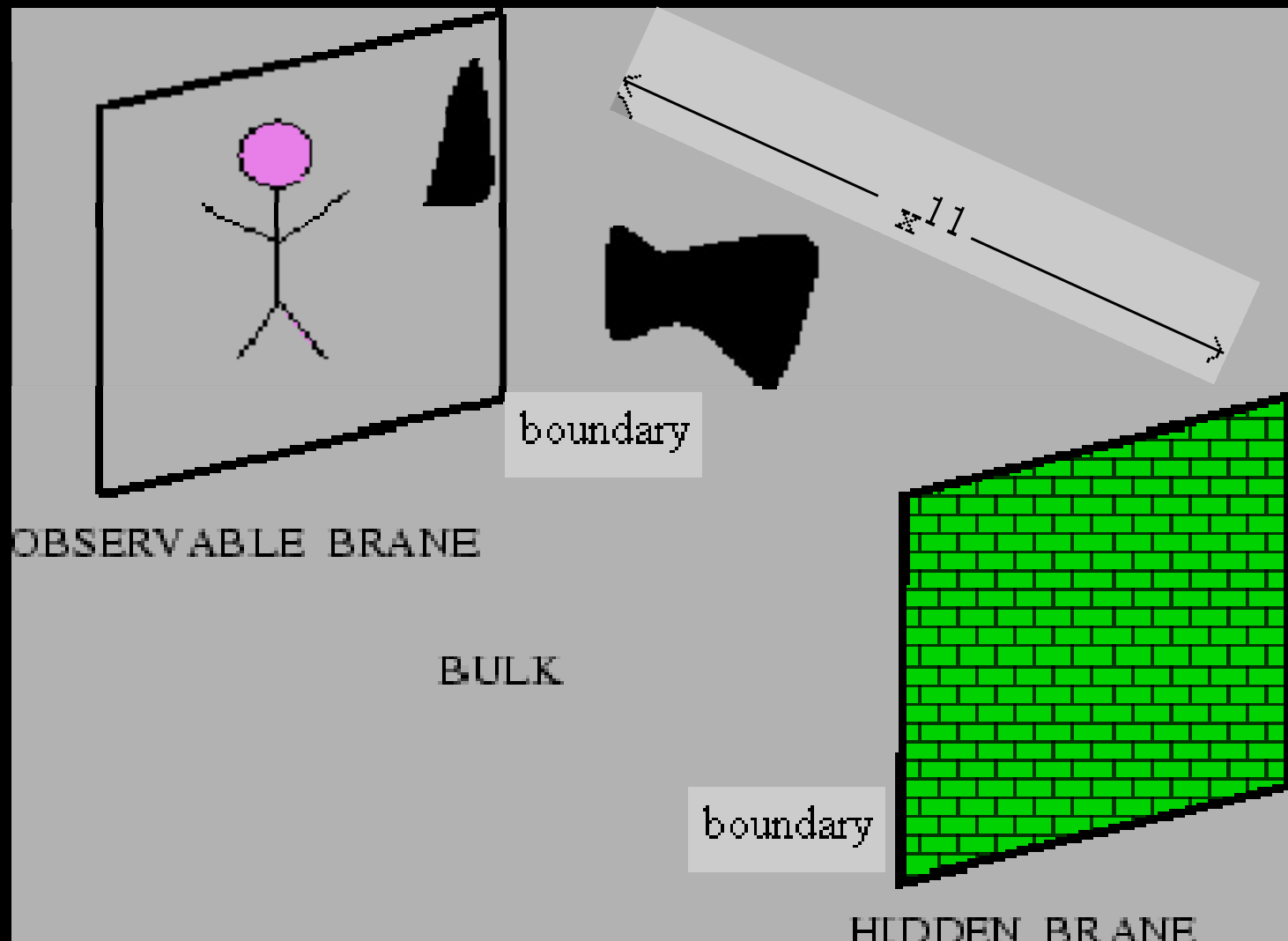


And with the appearance of an additional spatial dimension, quantum mechanical consistency required that the dimension of spacetime also increase by one to $10+1$ as well.

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



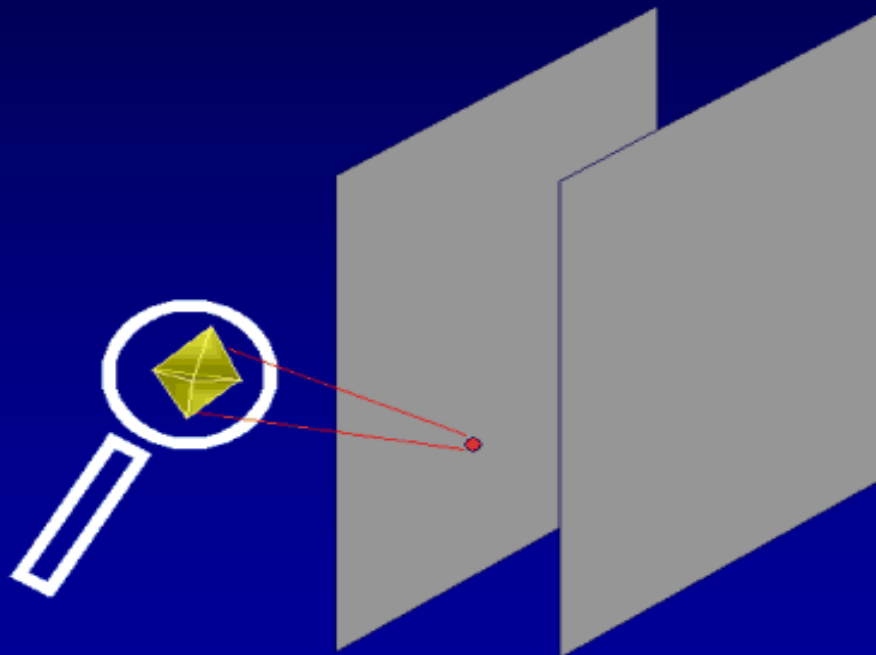
R. Brandenberger



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

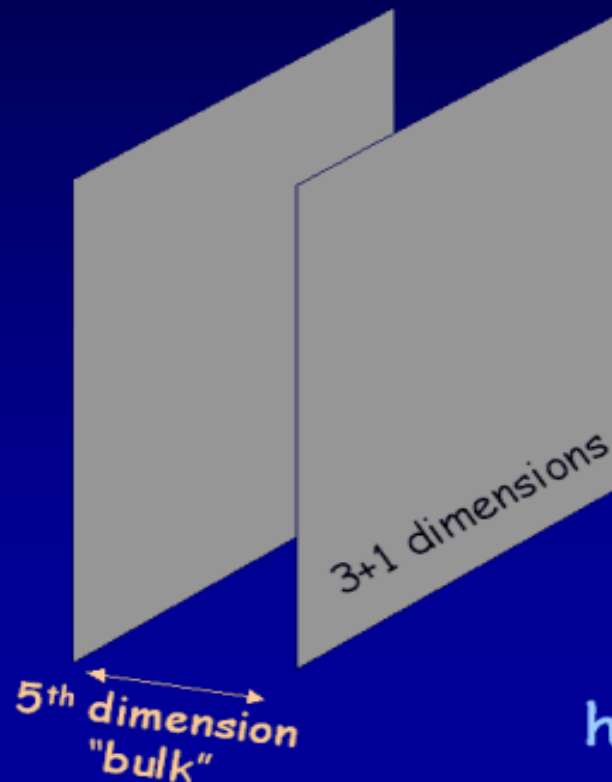


10+1 dimensions
compactify 6 dim.
on *C-Y* manifold

P. Horava & E. Witten
A. Lukas, B. Ovrut and D. Waldram

Effective 5-Dimensional Theory

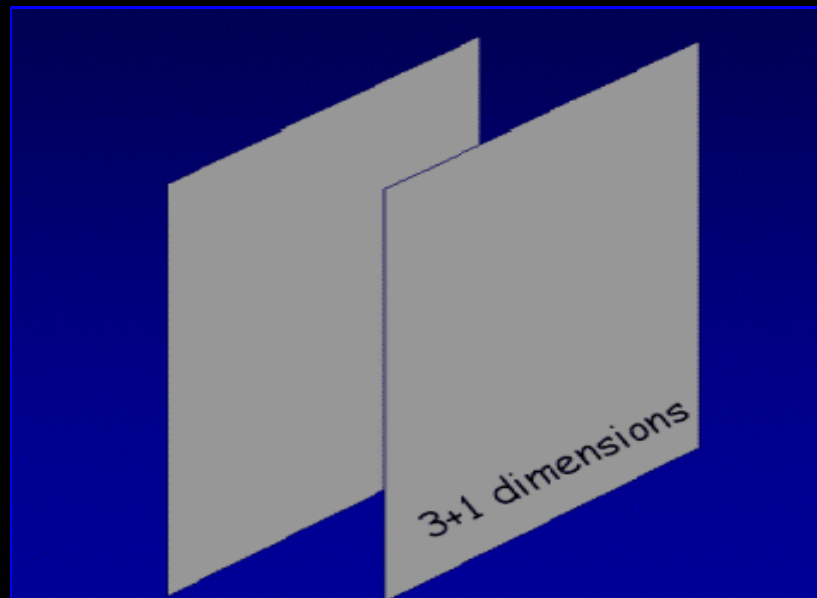
Motivations from String Theory/M-theory



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

heterotic M-theory

Size of 5th Dimension?

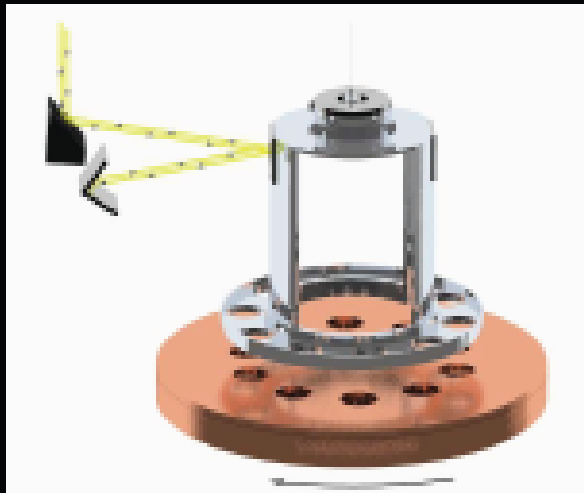


Horava et al.

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

Tests for sub-mm. directions

$$F_{\text{grav}} = -Gm_1m_2/r^2 \rightarrow -Gm_1m_2/r^{2+n}$$

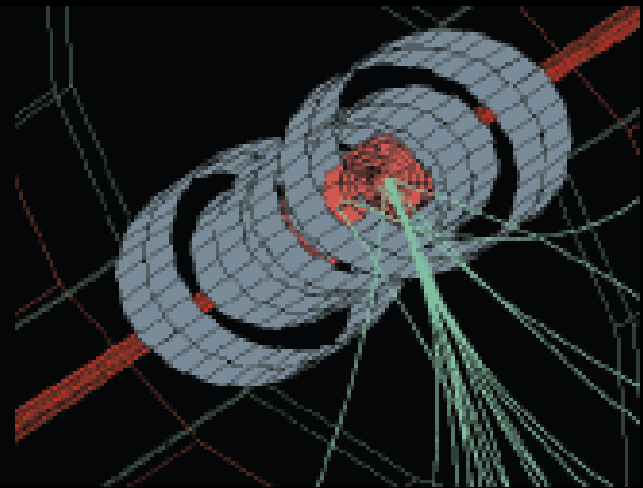


If gravity leaks into extra dimensions, **Newton's inverse-square law should break down at small distances** - gravity will be stronger than you think.

**Standard gravity verified down to 0.15 mm
at Univ. of Wash. with 97% confidence level**

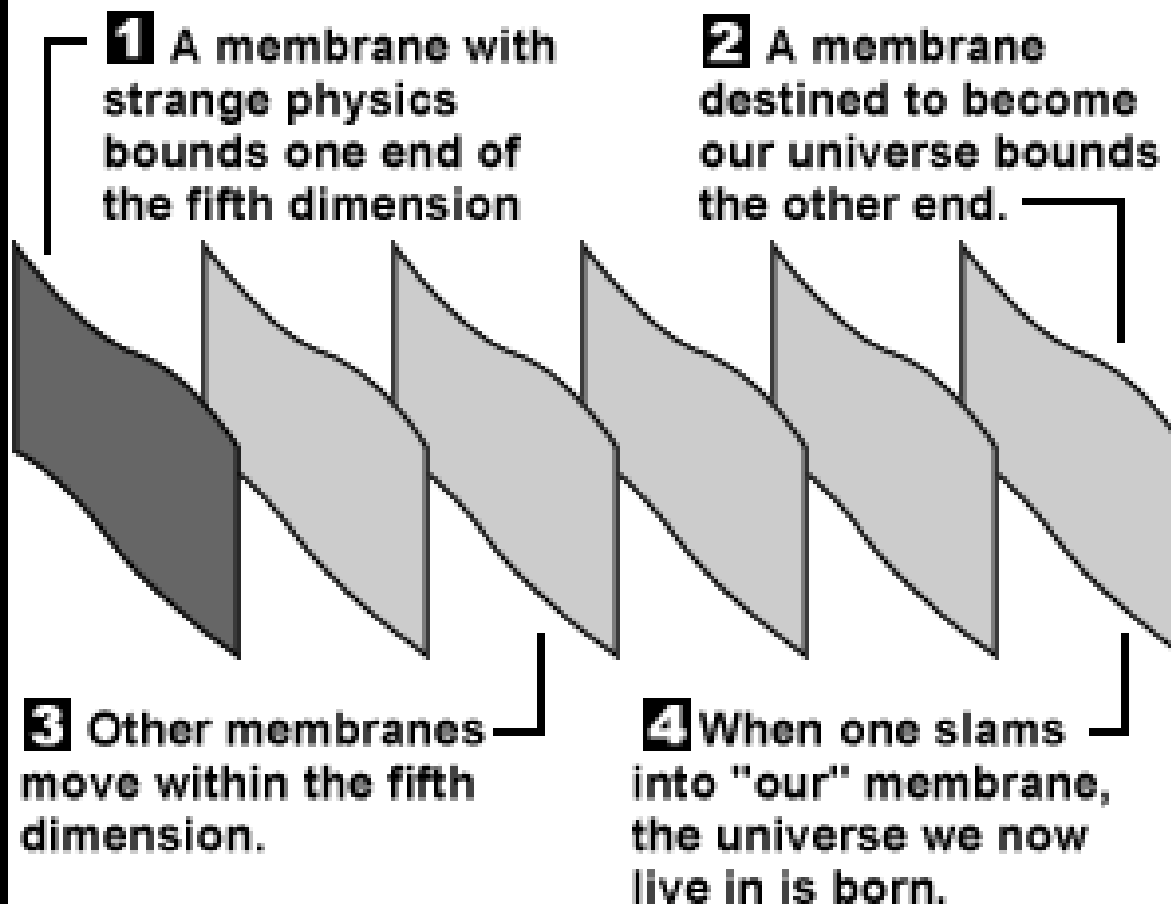
Manufacturing of Stringy Blackholes!

- 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

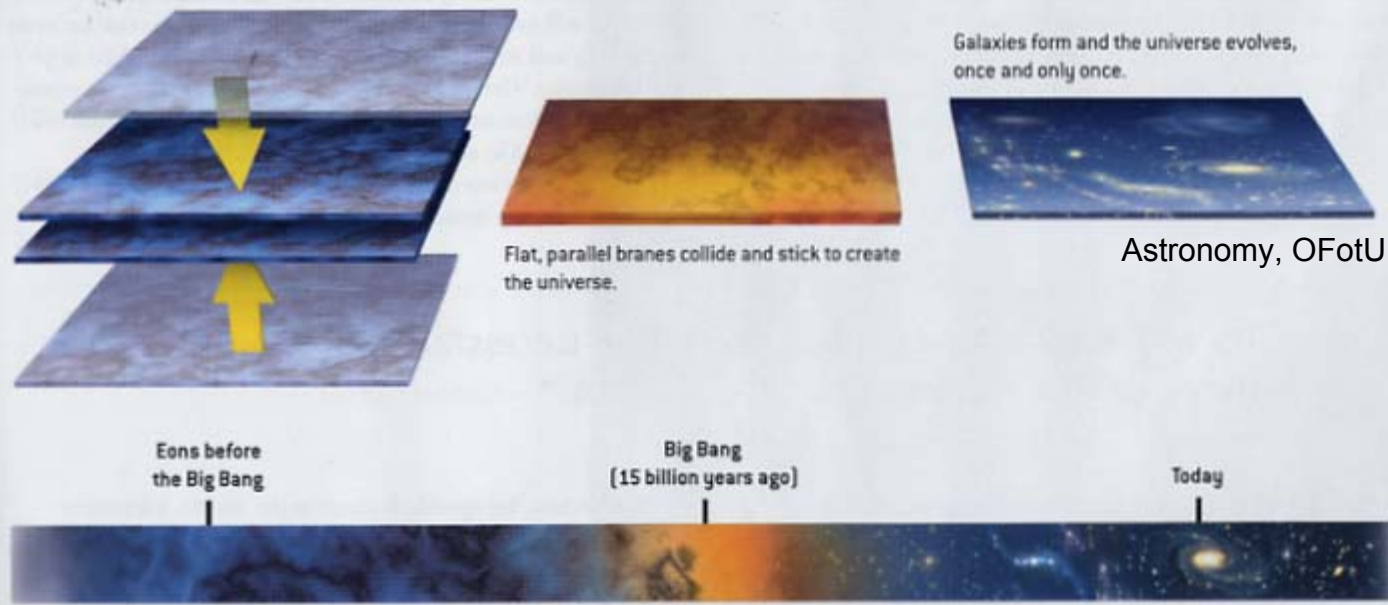


Proposed Explanation for Big Bang Implying Time Before Time!

Making an Ekpyrotic Universe

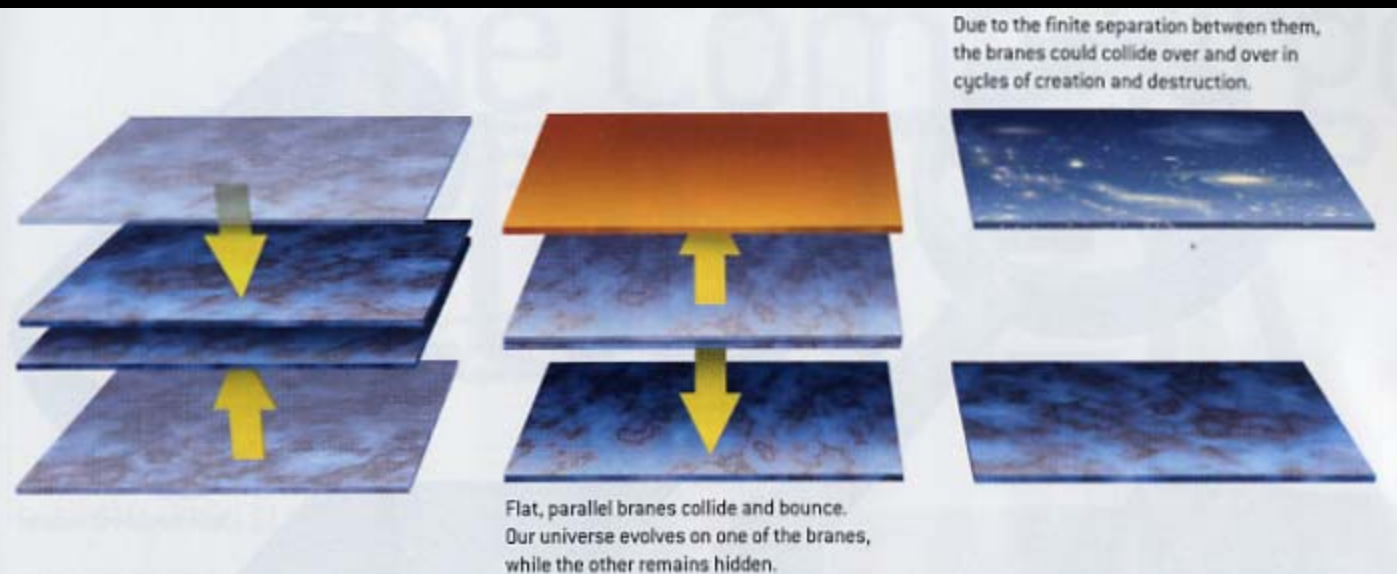


The Big Crash: Ekpyrotic model



Single
Event

Astronomy, OFotU



Cyclical
Events

The colliding Branes would not remain perfectly flat as they approach each other due to quantum effects.

Big Bang Inflation 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

C.C./dark energy

1

$(10^{18} \text{ GeV})^4$



10^{-120}

$(10^{-12} \text{ eV})^4$

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

new factor is M-theory effect

String/M Landscape

c.c./d.e. $(M_{\text{Pl}})^4$

At least 10^{500}
Possible String
Model Universes

de Sitter

1

0

Anti-de Sitter

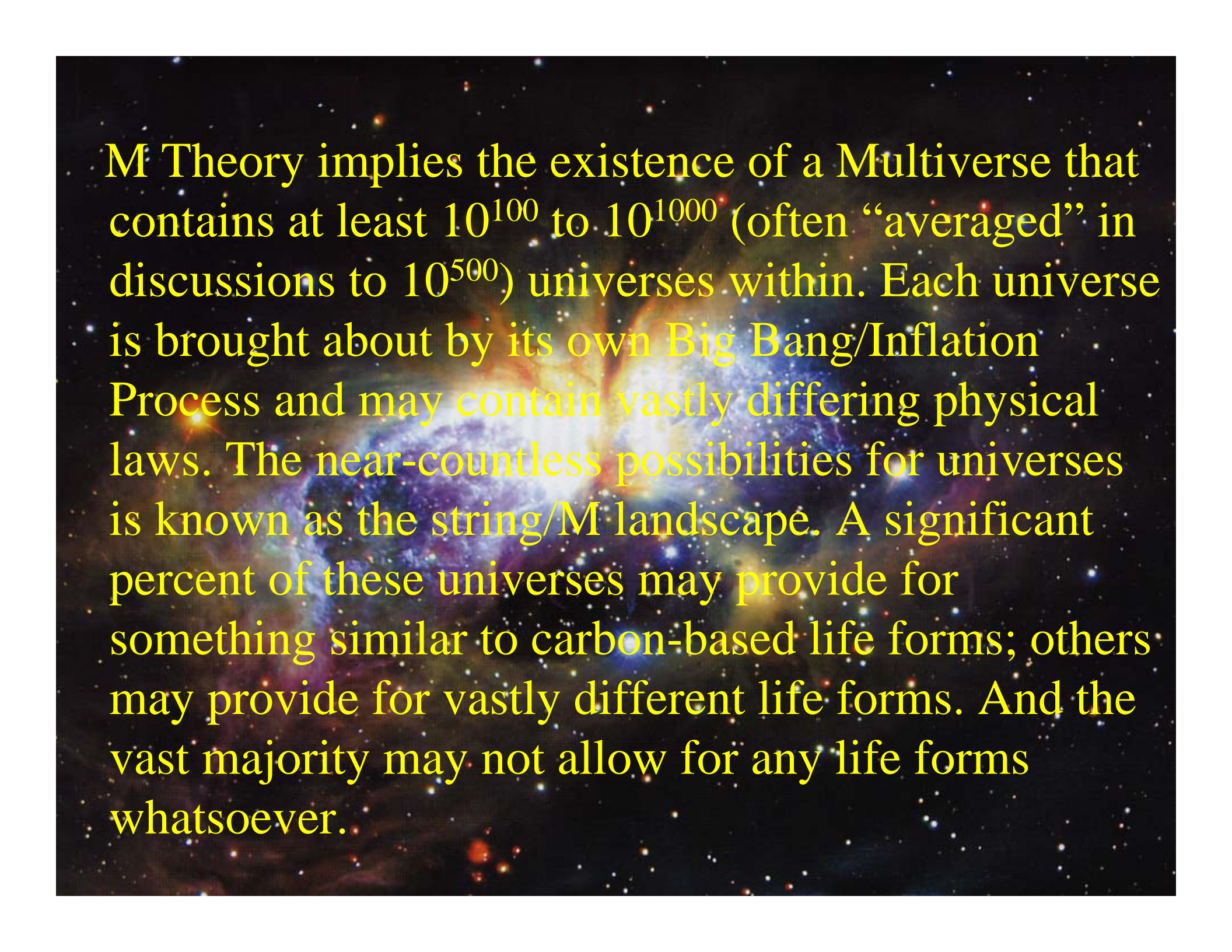
-1



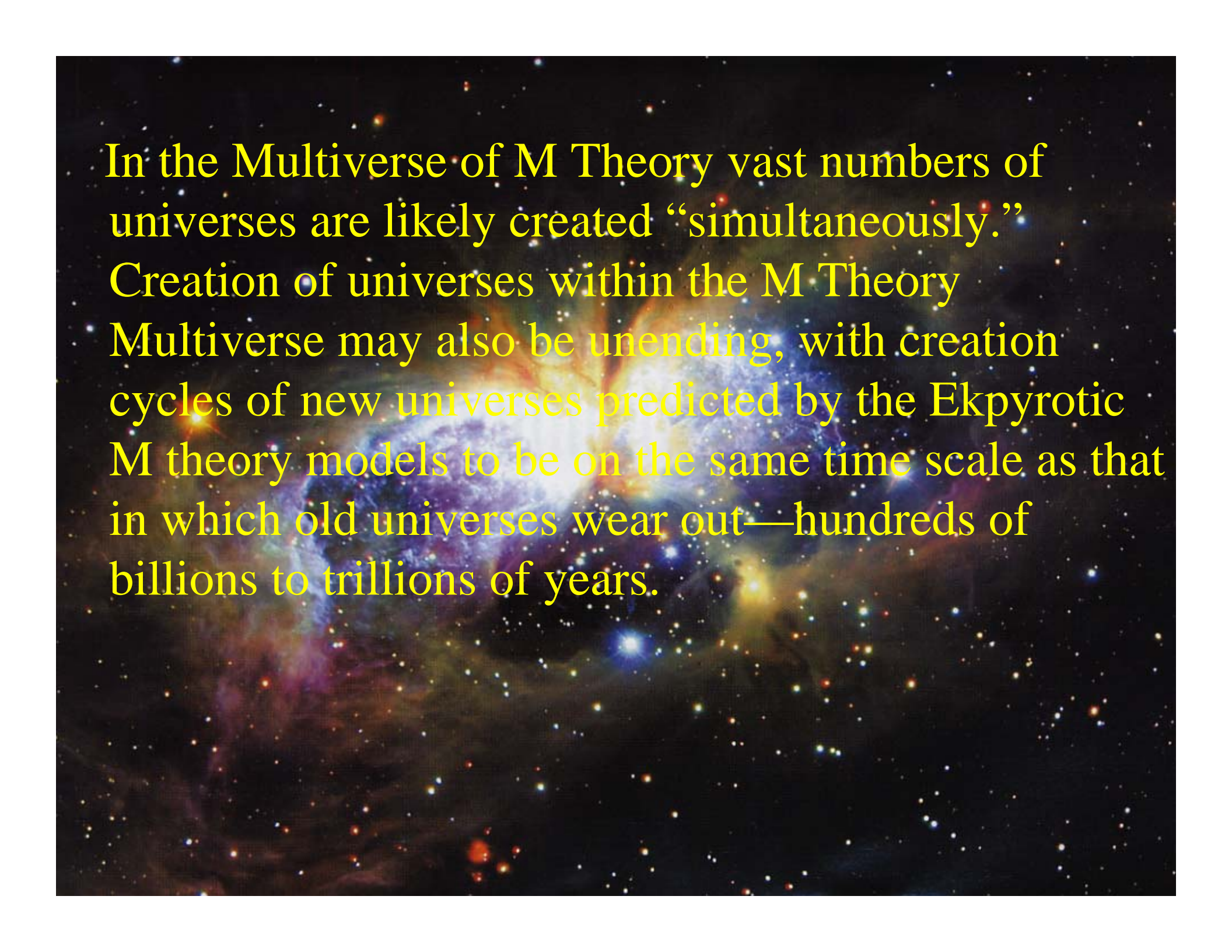
10^{-120}
Our universe

Excited modes w/
energy gaps of no
more than $10^{-120} M_{\text{Pl}}^4$

Vacuum near -1

The background of the slide is a deep space image featuring a dense field of stars and several prominent galaxies. A large, bright, and colorful nebula or galaxy core is visible in the center-left, with hues of orange, yellow, and blue. The surrounding space is dark, filled with numerous smaller, distant stars and fainter galactic structures.

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.