The String Landscape and the Multiverse

TAMU-Commerce, October 24

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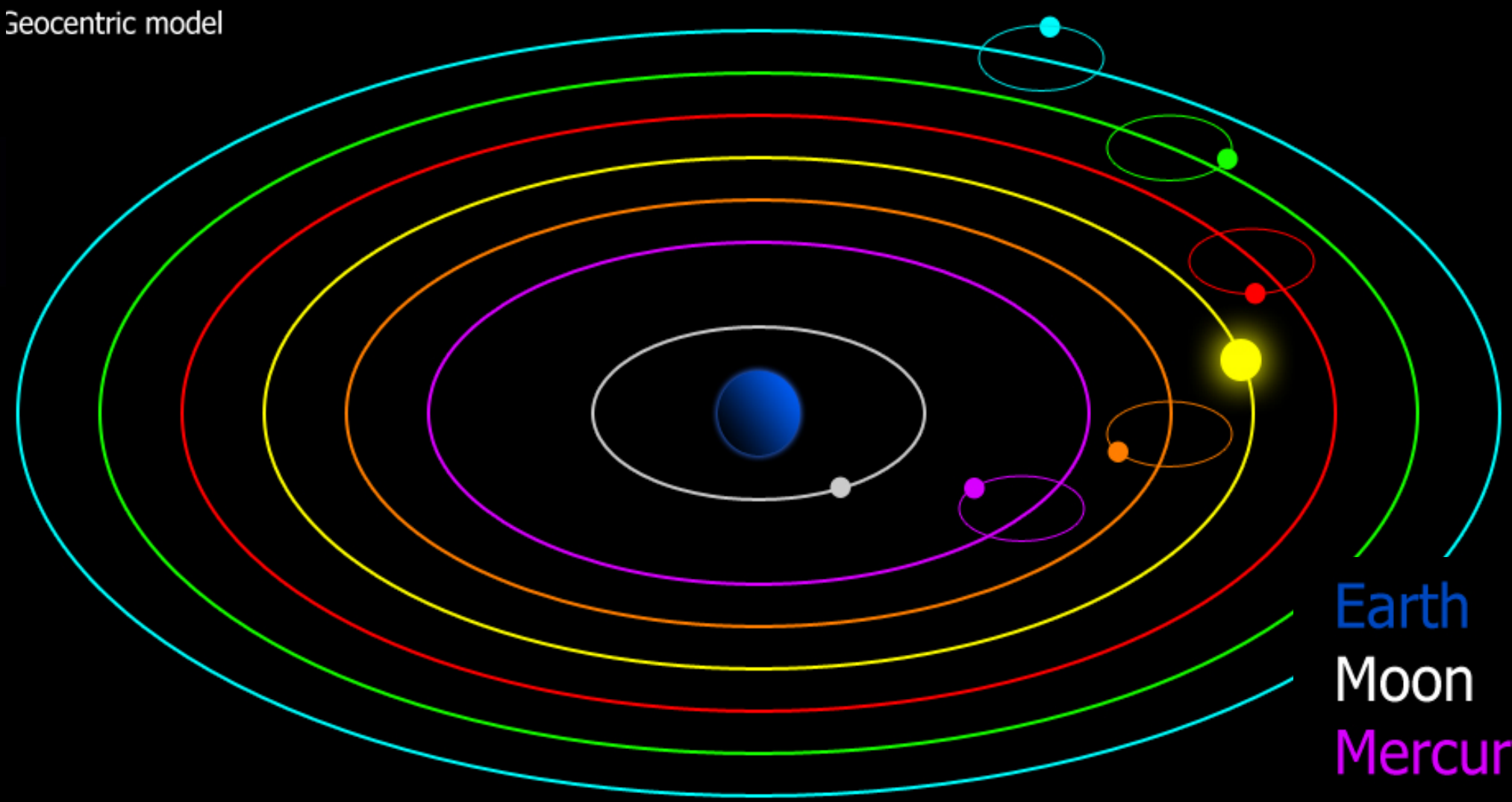
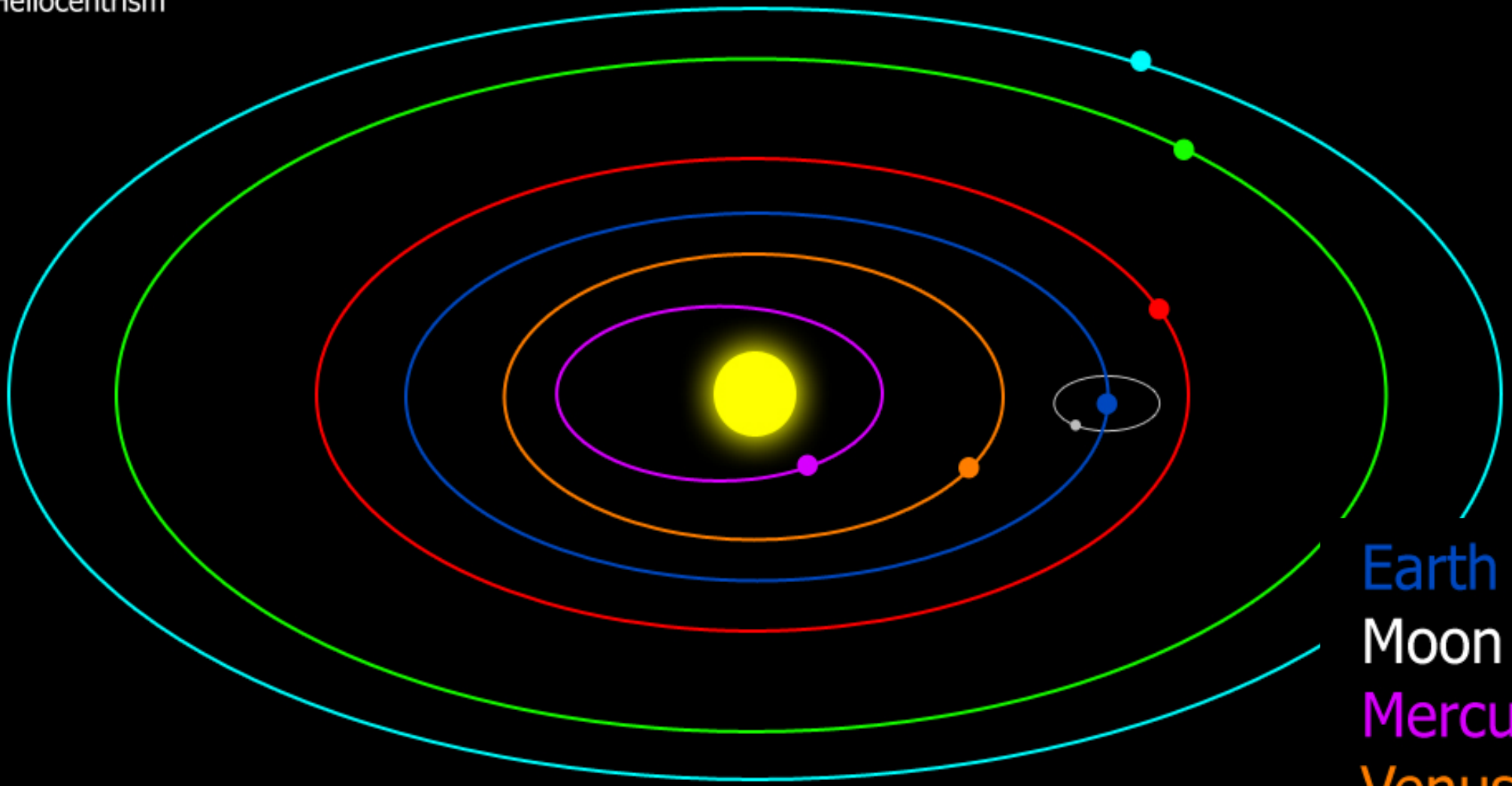
Baylor University
PHYSICS


The String Landscape & the Multiverse
a. Qucik History of Cosmology
b. Quick History of String Theory
b. Development of String Landscape
c. Life in the Multiverse



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

Heliocentrism



Earth
Moon
Mercury
Venus
Sun
Mars
Jupiter
Saturn

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.

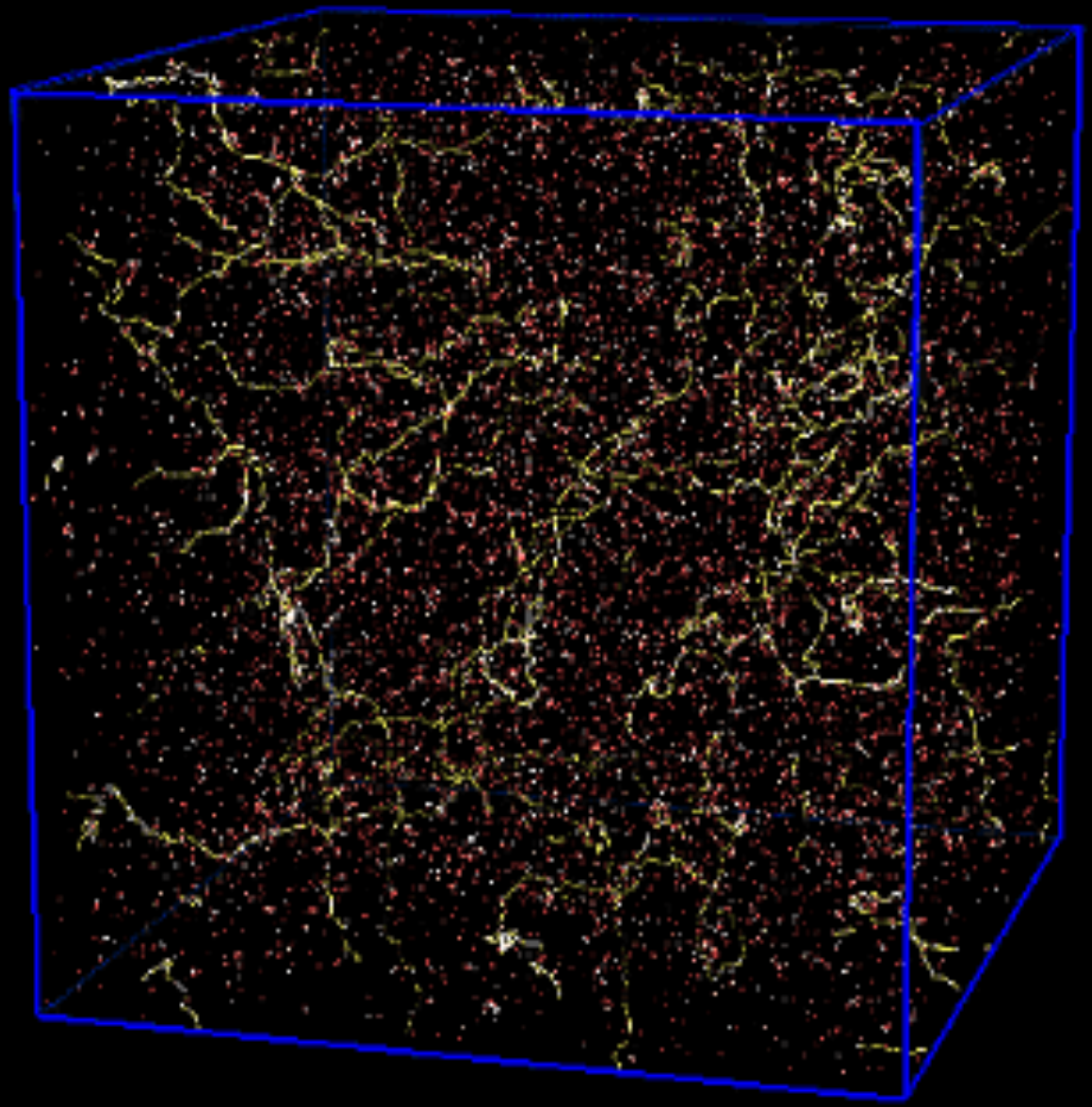
S. Carroll, http://pancake.uchicago.edu/~carroll


You are here

Visible Universe
(univercentric picture)

13.7 billion
light years
In diameter

= 8 x10^{22} mi

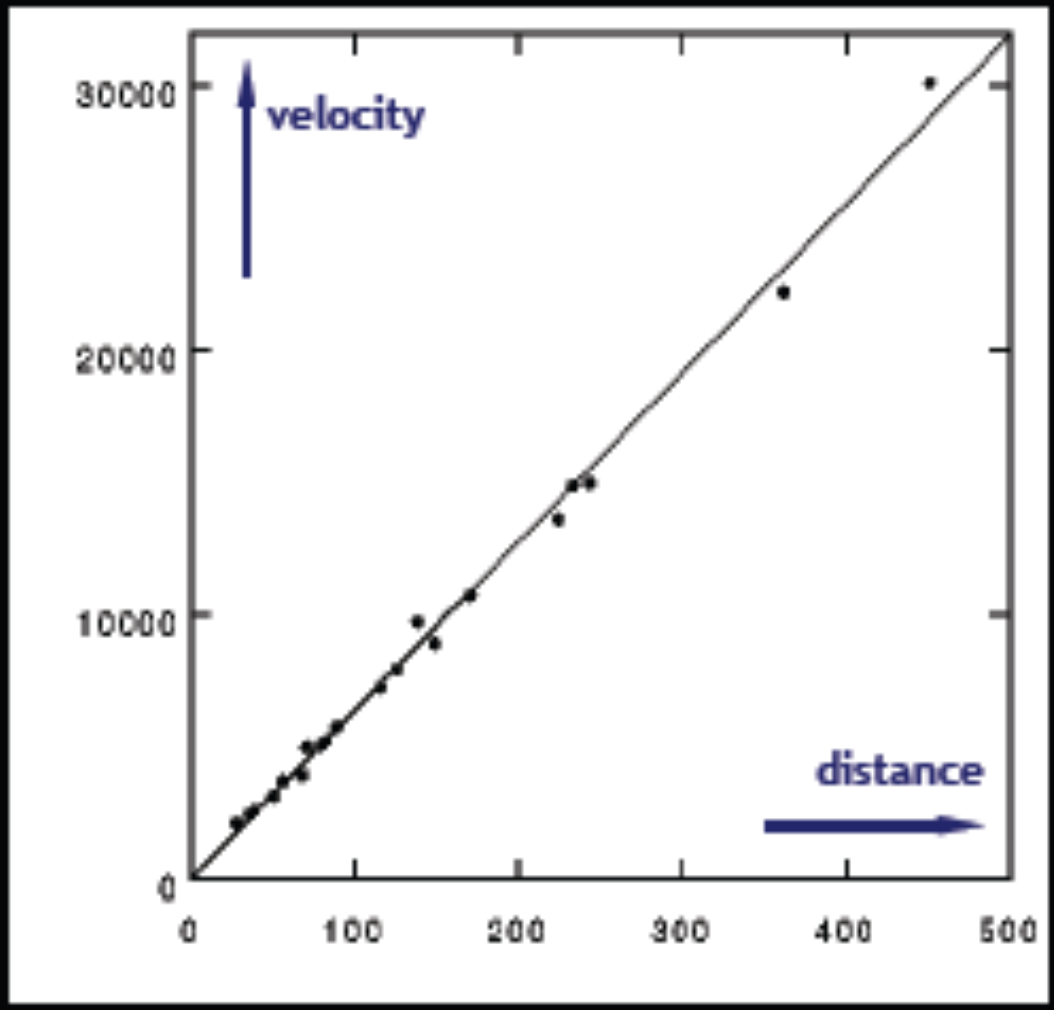


trillion galaxies,

trillion stars per
galaxy

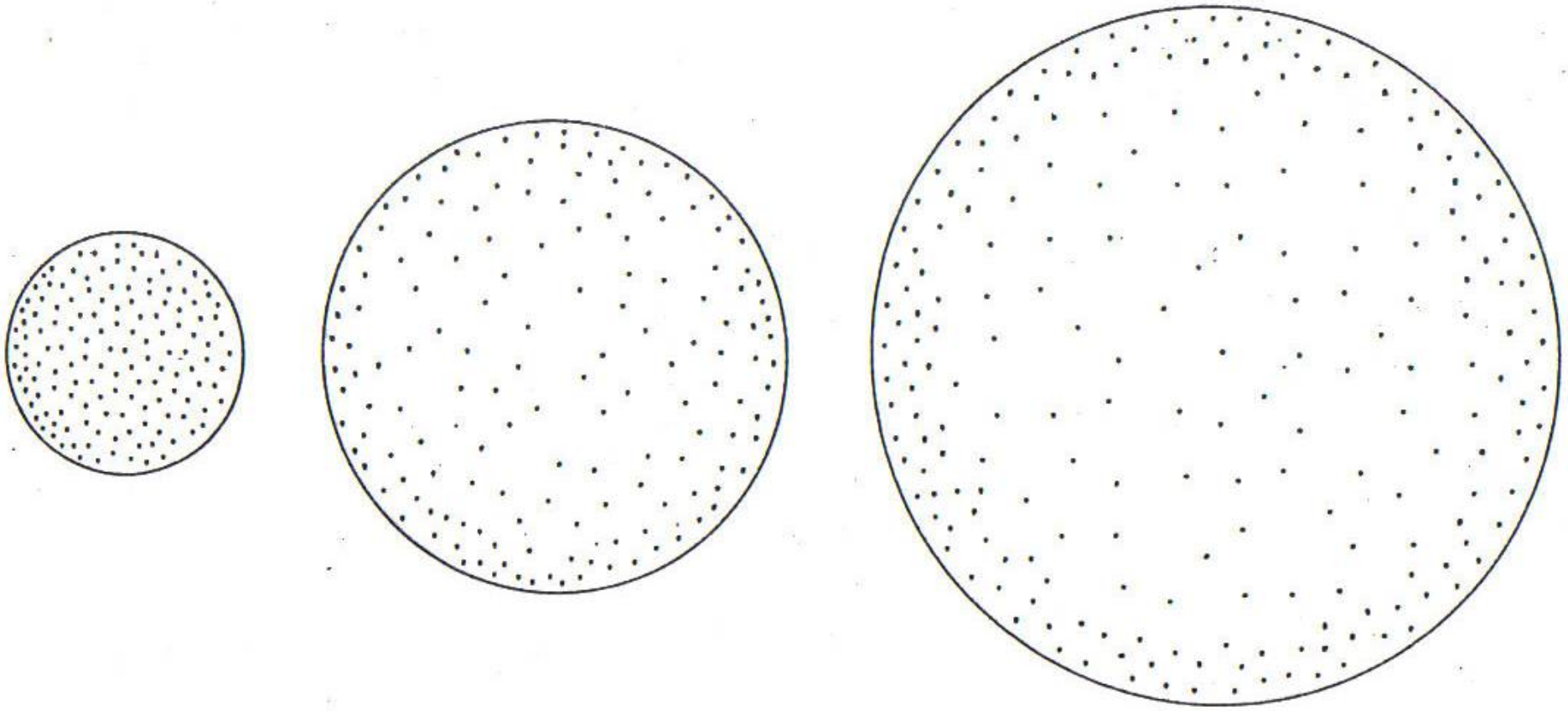
What is more: the universe is expanding.

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

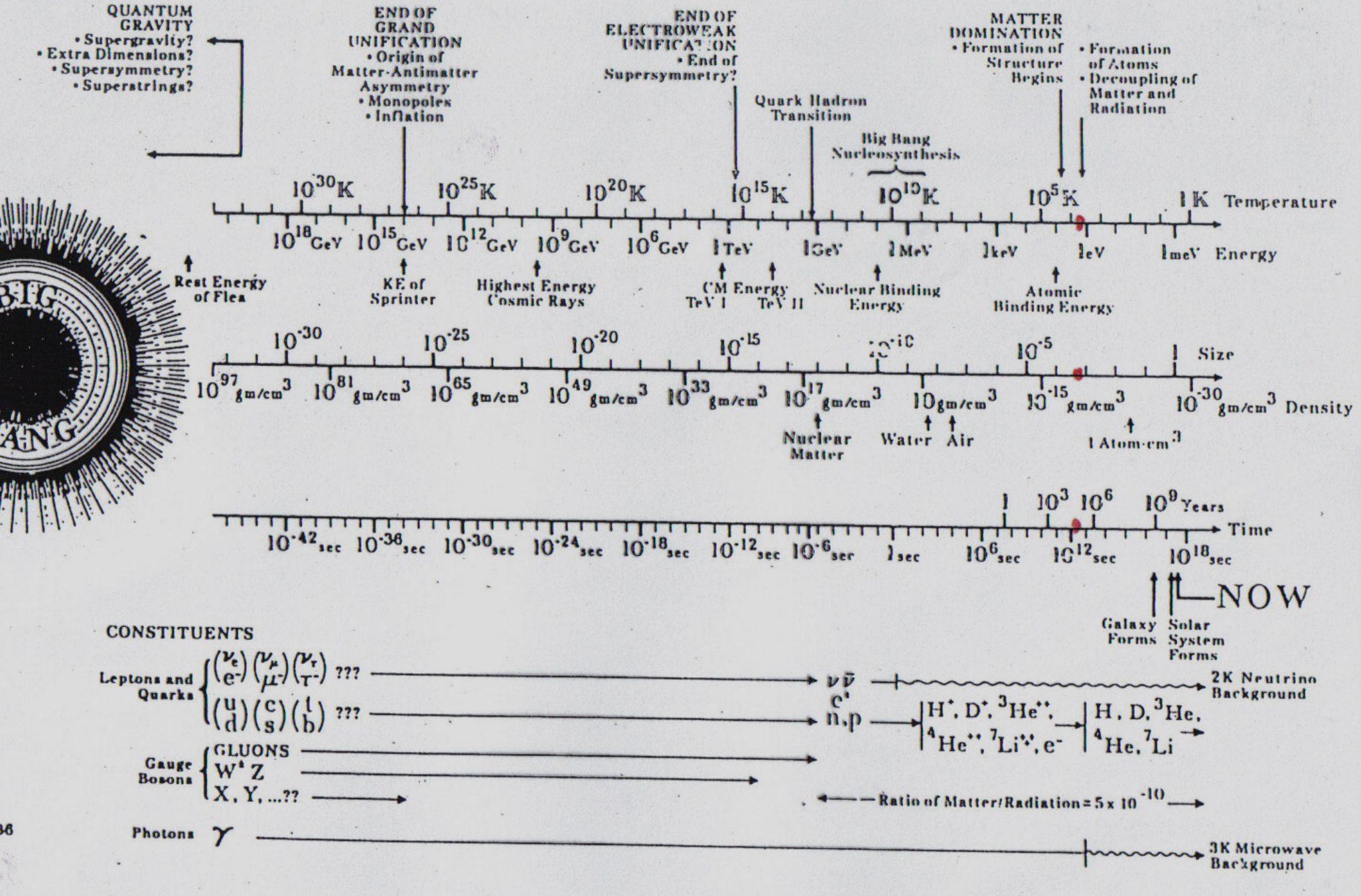


Modern version of Hubble's diagram.

S. Carroll, http://pancake.uchicago.edu/~carroll

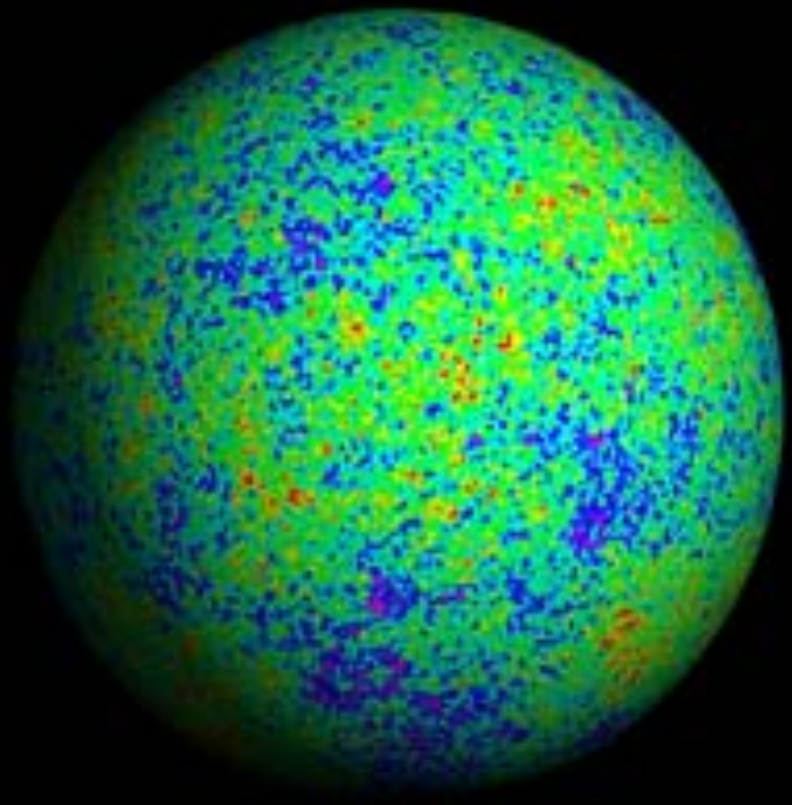


2 If three-dimensional space is represented by a two-dimensional surface, then one model of the expanding universe is reminiscent of a balloon that inflates from nothing. In this model space is finite, but unbounded: an observer in the space could travel freely all around the universe. The dots represent 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.


QUANTUM GRAVITY
• Supergravity?
• Extra Dimensions?
• Supersymmetry?
• Superstrings?
END OF GRAND UNIFICATION
• Origin of Matter-Antimatter Asymmetry
• Monopoles
• Inflation
END OF ELECTROWEAK UNIFICATION
• End of Supersymmetry?
Quark Hadron Transition
Big Bang Nucleosynthesis
MATTER DOMINATION
• Formation of Structure Begins
• Formation of Atoms
• Decoupling of Matter and Radiation
10^{30}K 10^{25}K 10^{20}K 10^{15}K 10^{10}K 10^{5}K 1K Temperature
10^{18}GeV 10^{15}GeV 10^{12}GeV 10^{9}GeV 10^{6}GeV 1TeV 1GeV 1MeV 1keV 1eV 1meV Energy
Rest Energy of Flea
KE of Sprinter
Highest Energy Cosmic Rays
CM Energy TeV I
TeV II
Nuclear Binding Energy
Atomic Binding Energy
10^{-30} 10^{-25} 10^{-20} 10^{-15} 10^{-5} 1 Size
10^{97} gm/cm^3 10^{81} gm/cm^3 10^{65} gm/cm^3 10^{49} gm/cm^3 10^{33} gm/cm^3 10^{17} gm/cm^3 10 gm/cm^3 10^{-15} gm/cm^3 10^{-30} gm/cm^3 Density
Nuclear Matter
Water
Air
1 Atom-cm^3
1 10^3 10^6 10^9 Years
10^{-42}sec 10^{-36}sec 10^{-30}sec 10^{-24}sec 10^{-18}sec 10^{-12}sec 10^{-6}sec 1sec 10^{6}sec 10^{12}sec 10^{18}sec Time
NOW
Galaxy Forms
Solar System Forms
CONSTITUENTS
Leptons and Quarks
$\begin{pmatrix}\nu_e\\e^-\end{pmatrix}\begin{pmatrix}\nu_\mu\\\mu^-\end{pmatrix}\begin{pmatrix}\nu_\tau\\\tau^-\end{pmatrix}$???
$\begin{pmatrix}u\\d\end{pmatrix}\begin{pmatrix}c\\s\end{pmatrix}\begin{pmatrix}t\\b\end{pmatrix}$???
$\nu\bar{\nu}$
c^*
n, p
H^+, D^+, $^3He^{++}$, $^4He^{++}$, $^7Li^{+++}$, e^-
H, D, ^{3}He, ^{4}He, ^{7}Li
2K Neutrino Background
Gauge Bosons
GLUONS
$W^\pm Z$
X, Y, ...??
Ratio of Matter/Radiation = 5×10^{-10}
Photons γ
3K Microwave Background

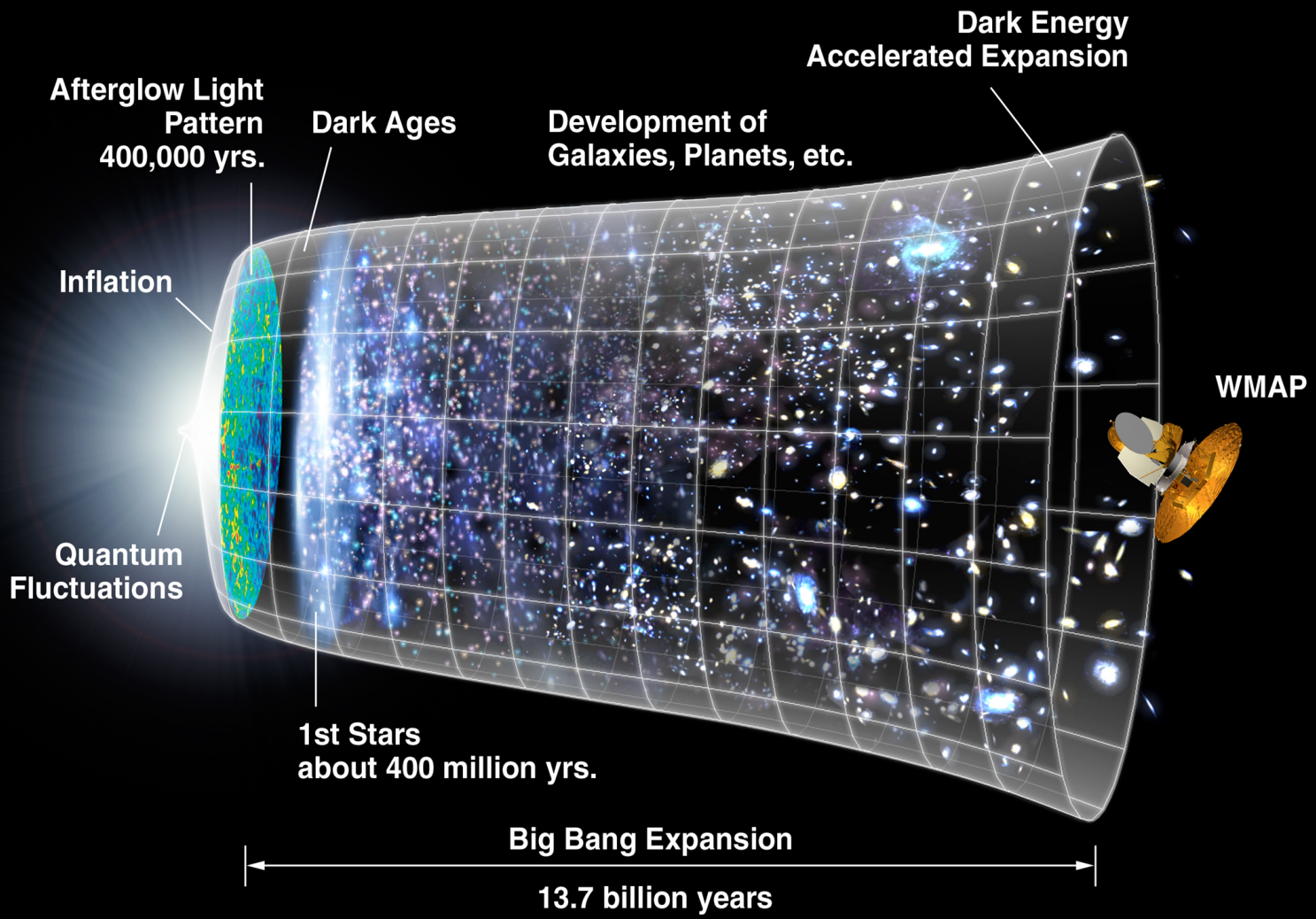
Cosmic Microwave Background

Present CMB Temp
= 2.73 Degrees above
absolute zero

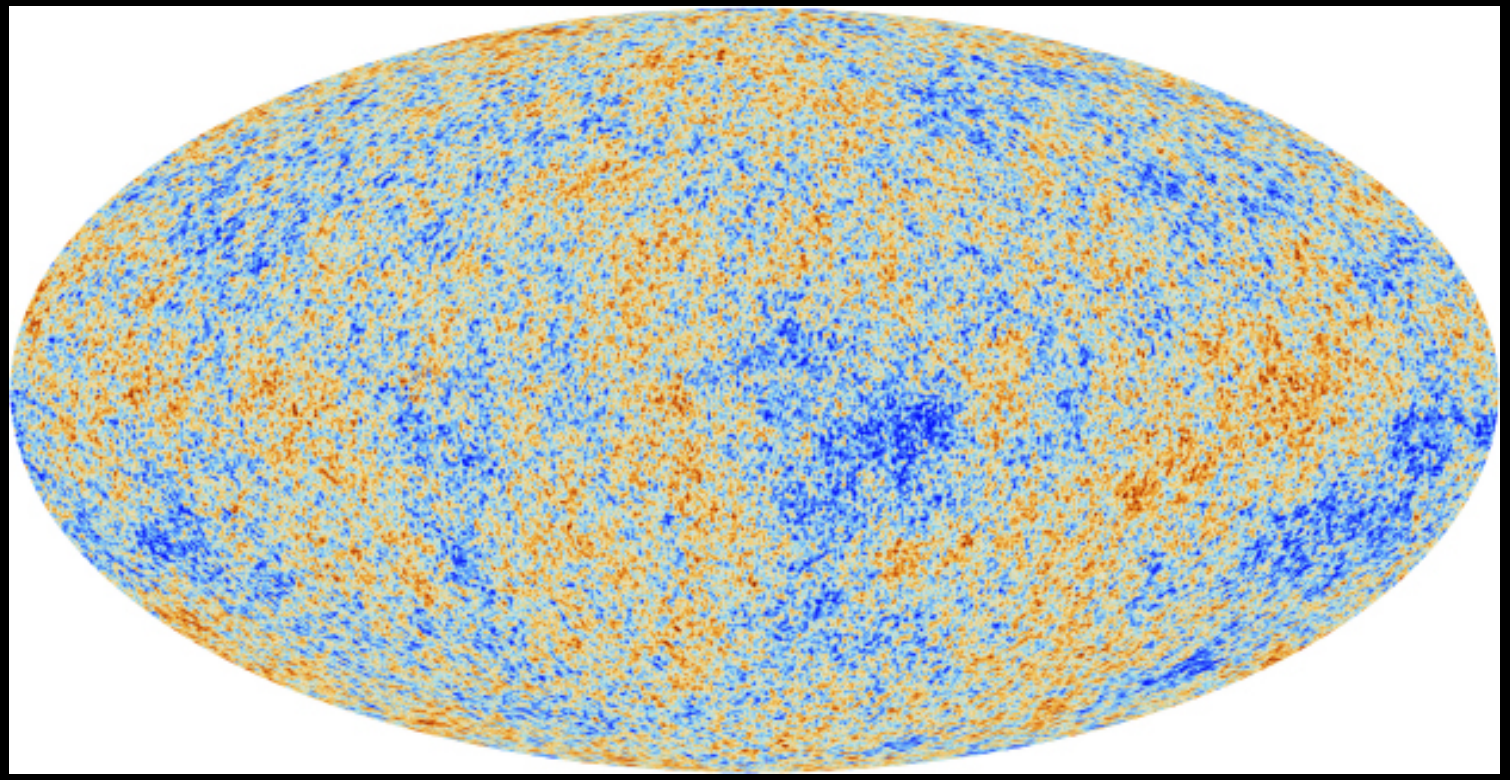


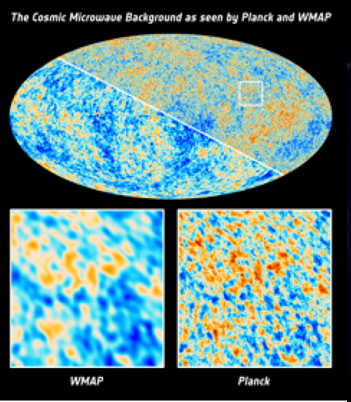
WMAP:
Temp variations
of 1 part in 100,000
denoted by color
variations

Blue is hottest,
Red is coldest



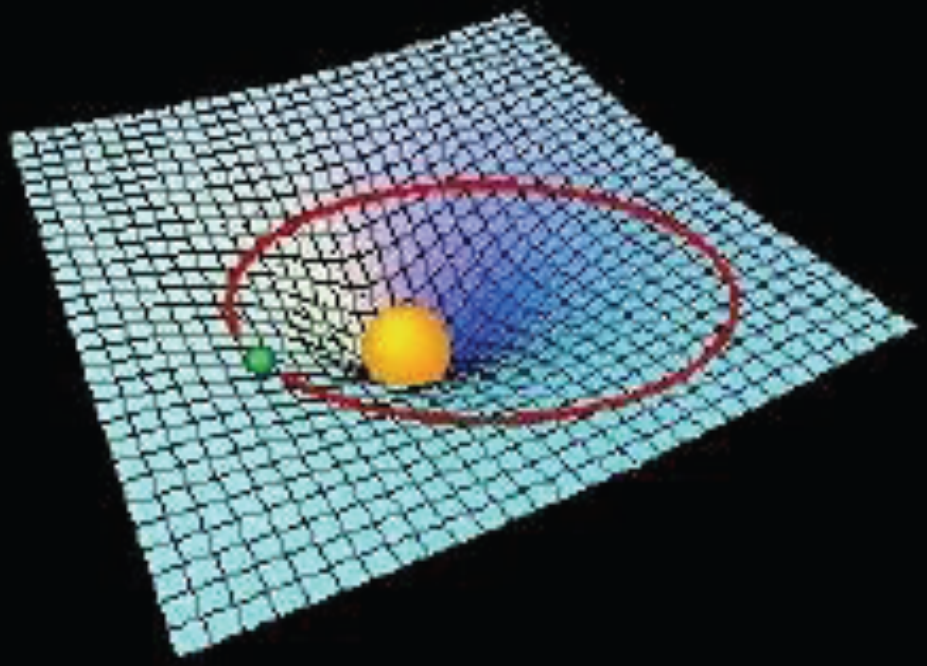
CMB (Planck)




The Cosmic Microwave Background as seen by Planck and WMAP
WMAP
Planck

How do we know that what we see is all there is?

There may be stuff in the universe we can't see -- both invisible and transparent. How could we detect such stuff? Gravity. Explained by Einstein as arising from the curvature of spacetime.



The special feature of gravity is that everything causes gravity, in direct proportion to how much energy it contains. You can't hide from gravity!

S. Carroll, http://pancake.uchicago.edu/~carroll

This suggests a way to search for invisible matter:

gravitational lensing.

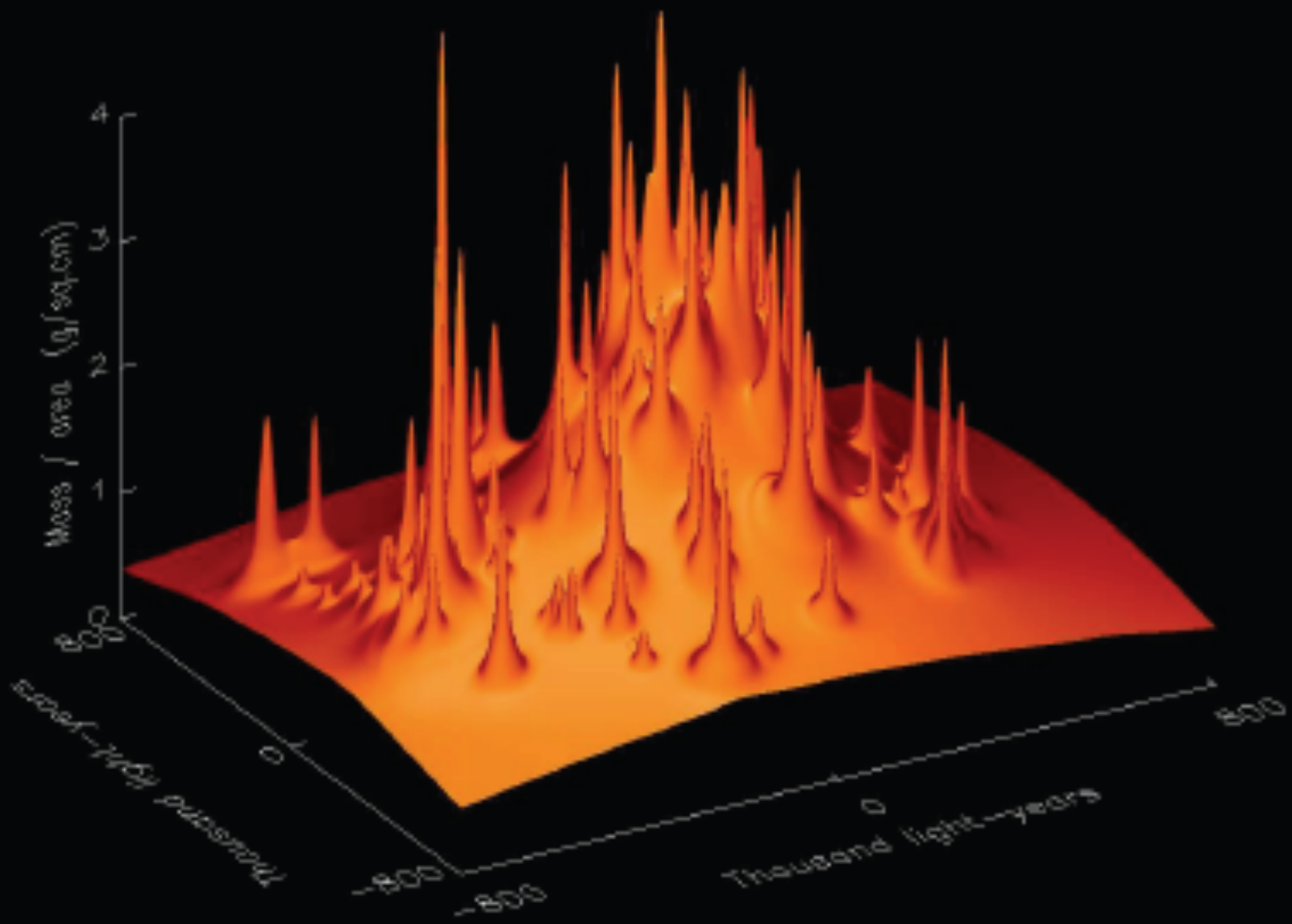
The gravitational field of a galaxy (or cluster of galaxies) deflects passing light; the more mass, the greater deflection.

So we can infer the existence of matter even if we can't see it.

S. Carroll, http://pancake.uchicago.edu/~carroll

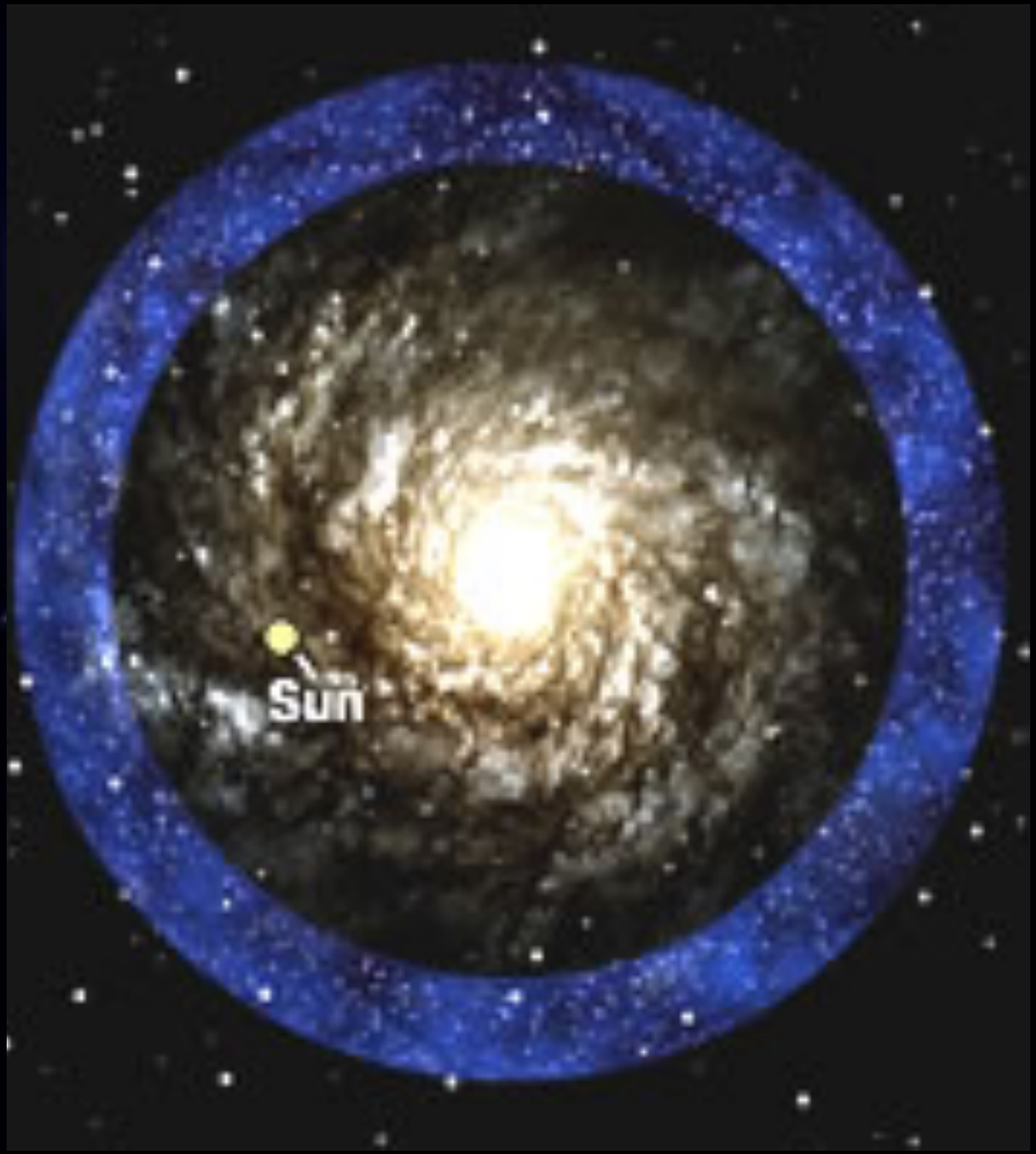
Hubble Space Telescope image of a cluster of galaxies.
An irregular blue galaxy in the background is multiply-imaged.

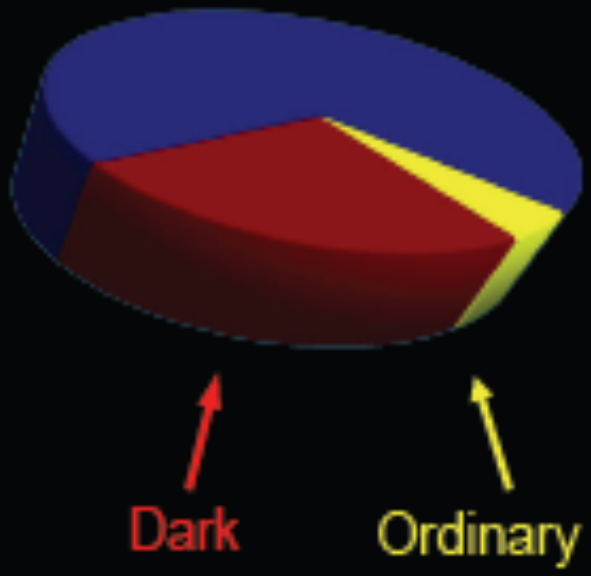
S. Carroll, http://pancake.uchicago.edu/~carroll



Mass reconstruction of the cluster. Note the large, smooth distribution of (apparently invisible) matter.

S. Carroll, http://pancake.uchicago.edu/~carroll


Sun

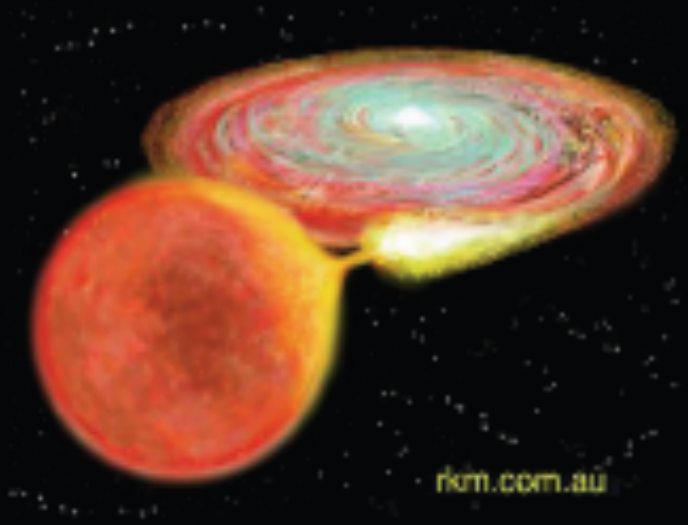


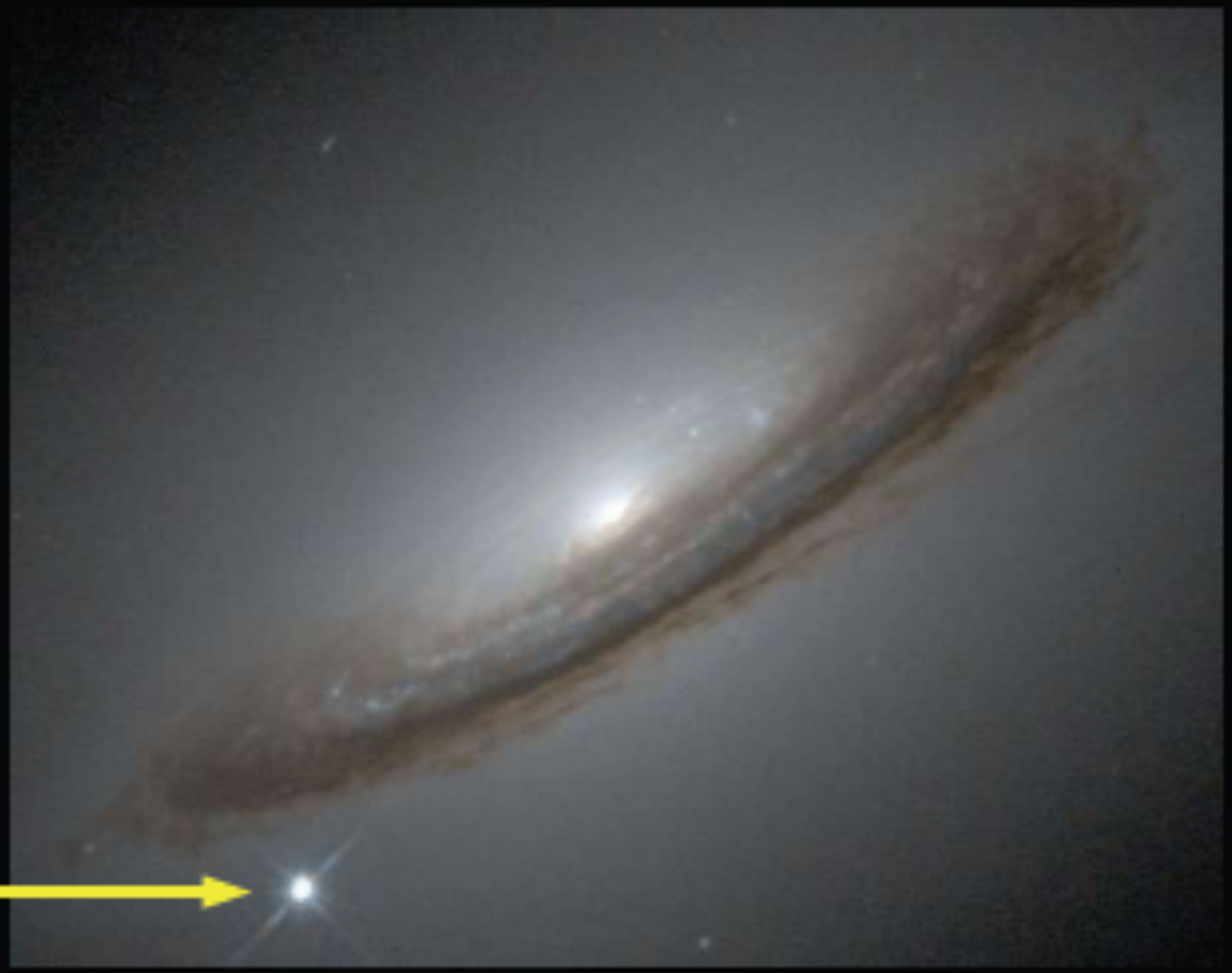
Even stranger, the dark matter isn't made of ordinary atoms - it's a completely new kind of particle.

Something that's heavy, but nevertheless stable (doesn't decay).

S. Carroll, http://pancake.uchicago.edu/~carroll

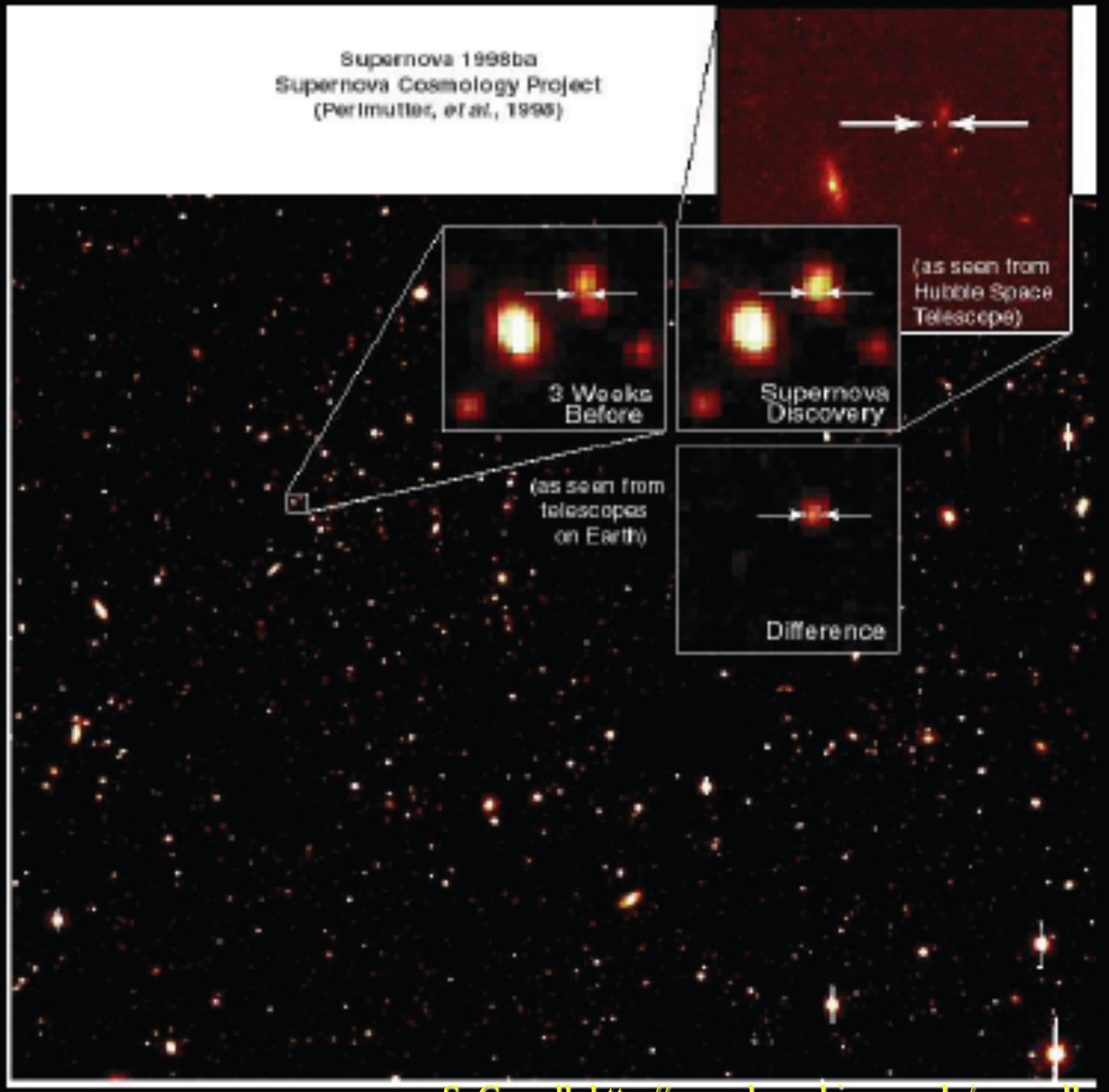
To track the expansion rate, use Supernovae (exploding white dwarf stars) as standard candles.





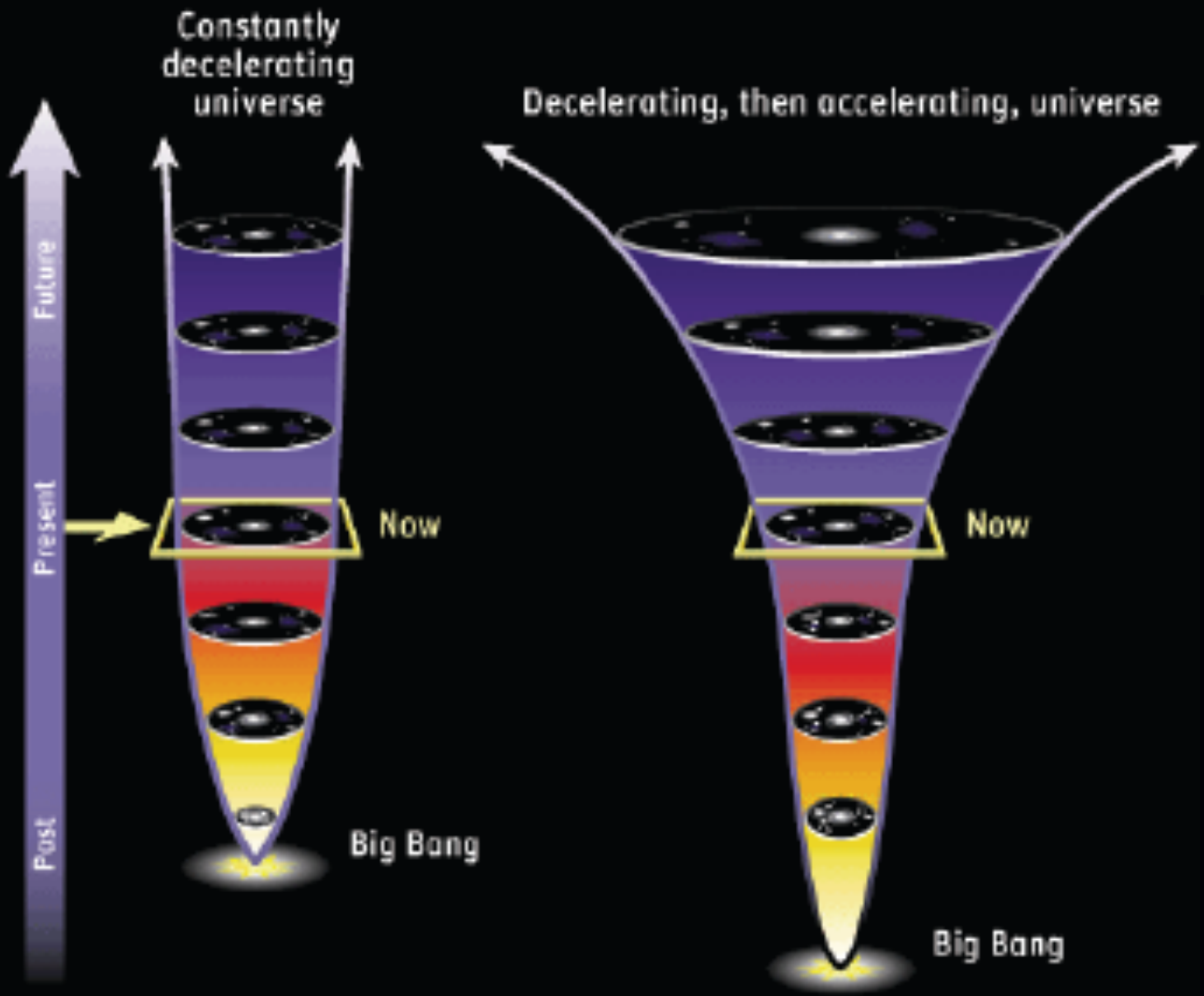
S. Carroll, http://pancake.uchicago.edu/~carroll

Strategy: stare at one patch of the sky for a long time, waiting for a star to blow up.



S. Carroll, http://pancake.uchicago.edu/~carroll

Result: the universe is actually accelerating, not slowing down at all!



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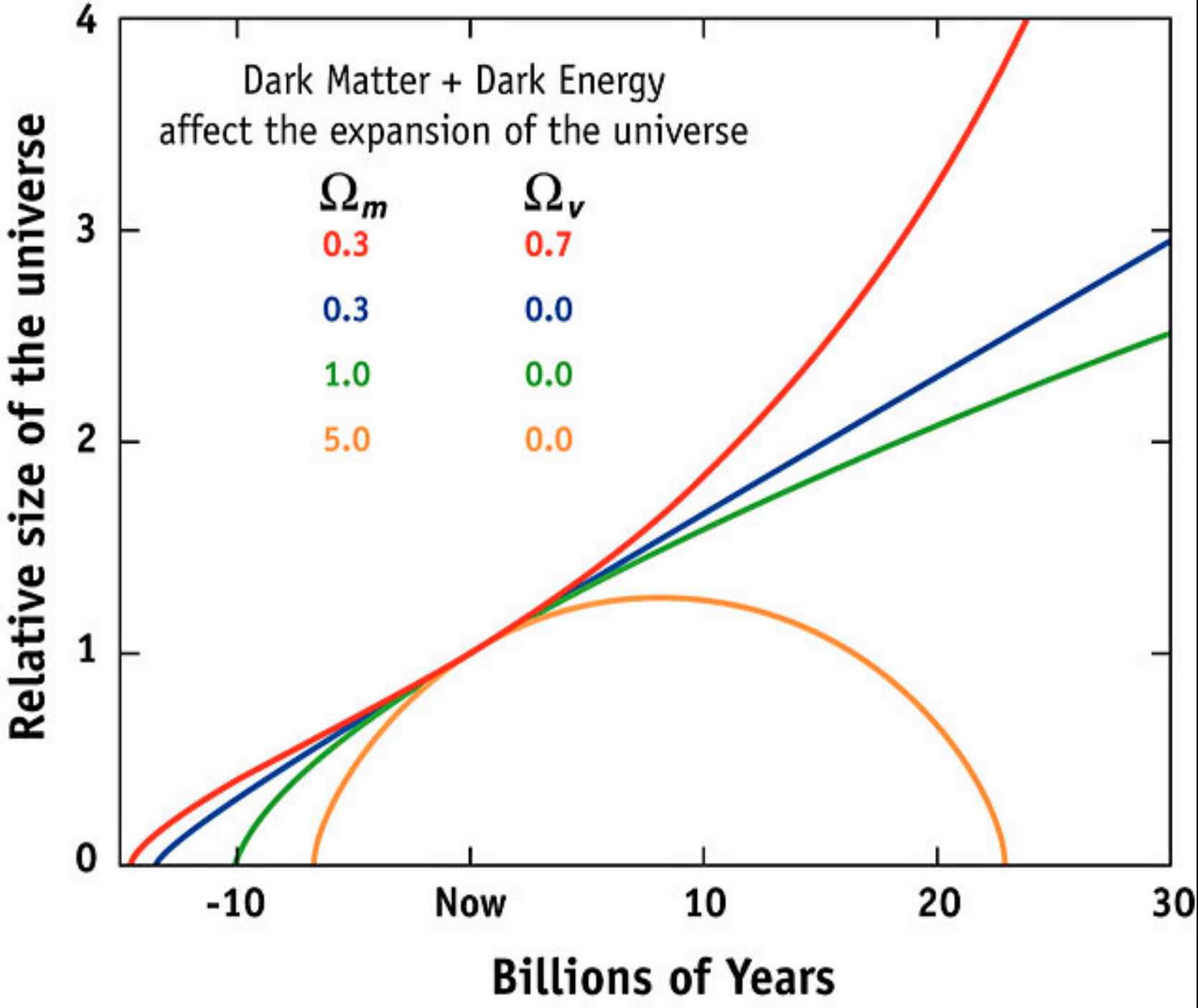
Expansion of the Universe



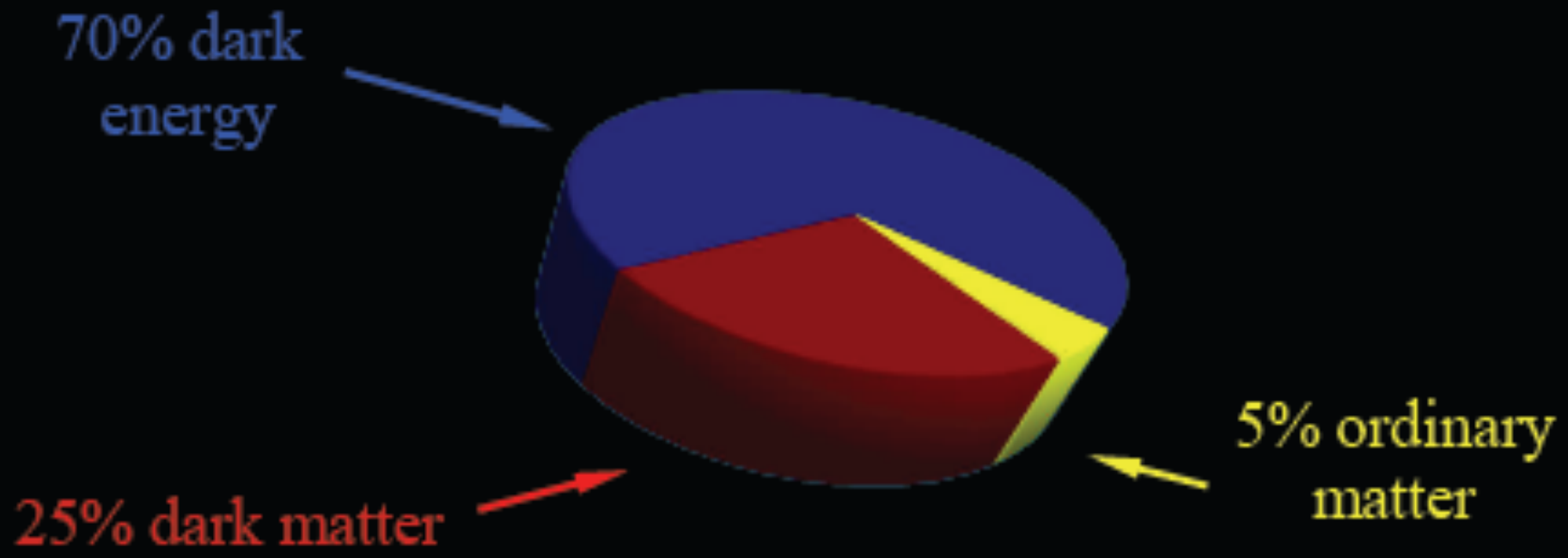
What would make the universe accelerate?

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

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?

S. Carroll, http://pancake.uchicago.edu/~carroll

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

So we know a great deal:

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

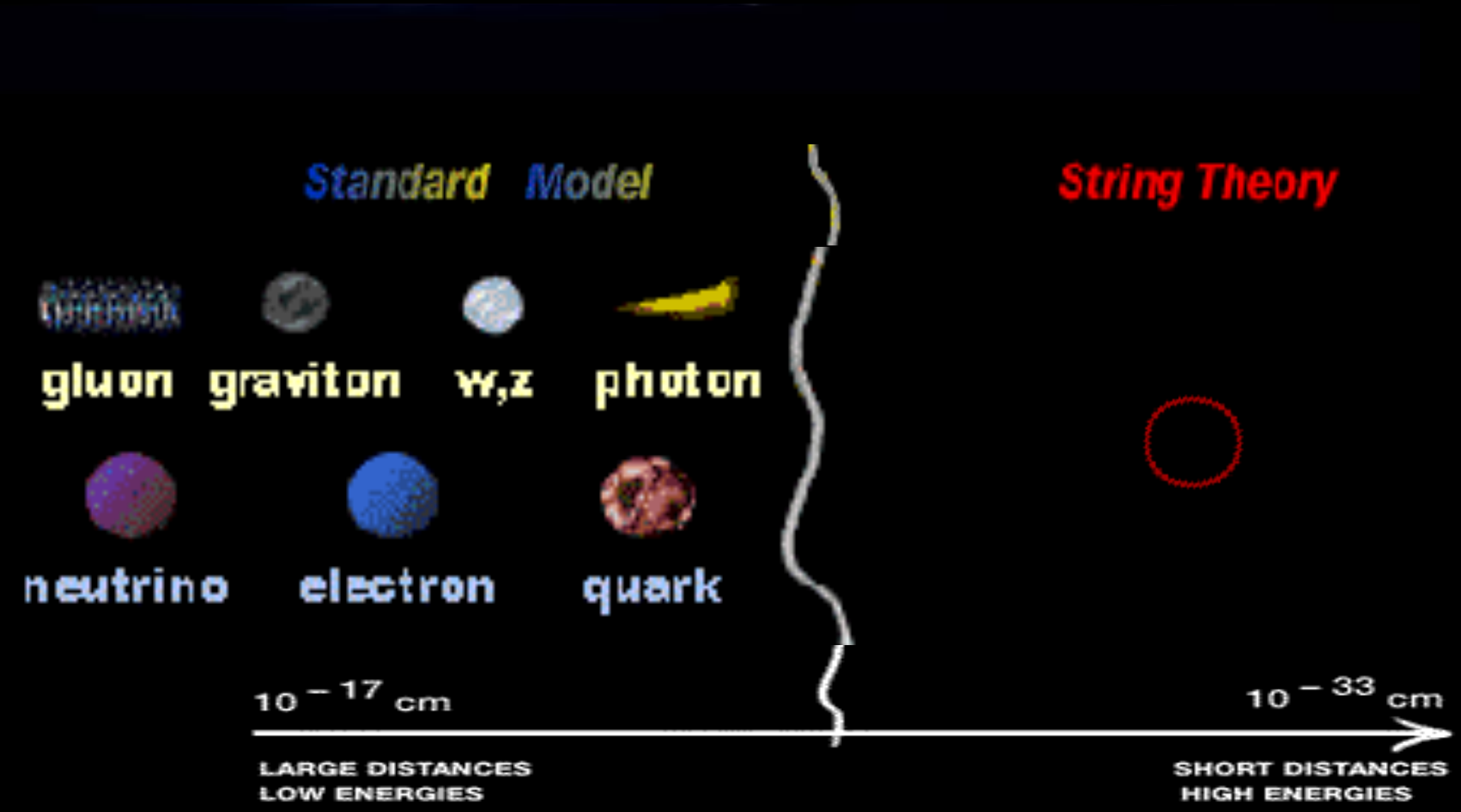
But deep puzzles remain:

- 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.


Proposed solution
String/M-Theory
www.baylor.edu/~CASPER
www.inet.hr/~tstimac/artwork.htm

All Matter & Forces in the Universe Unified by String Theory



Particles & Forces
Like Notes on a Violin String

A

B

C

D

E

F

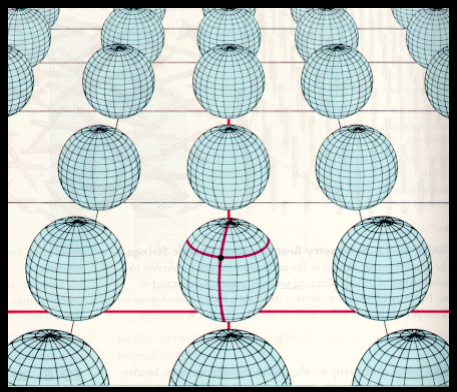
G

9 Dim → 3 Large Dim
+ 6 Compact Dim

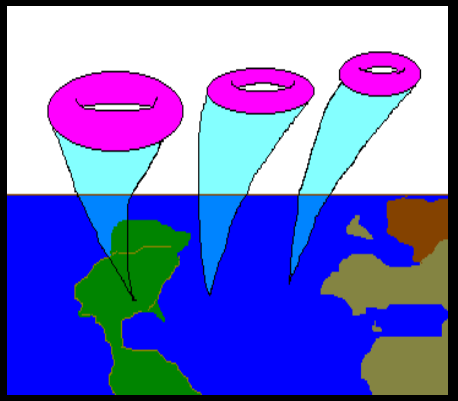
Products of 6 Circular Directions

Forming

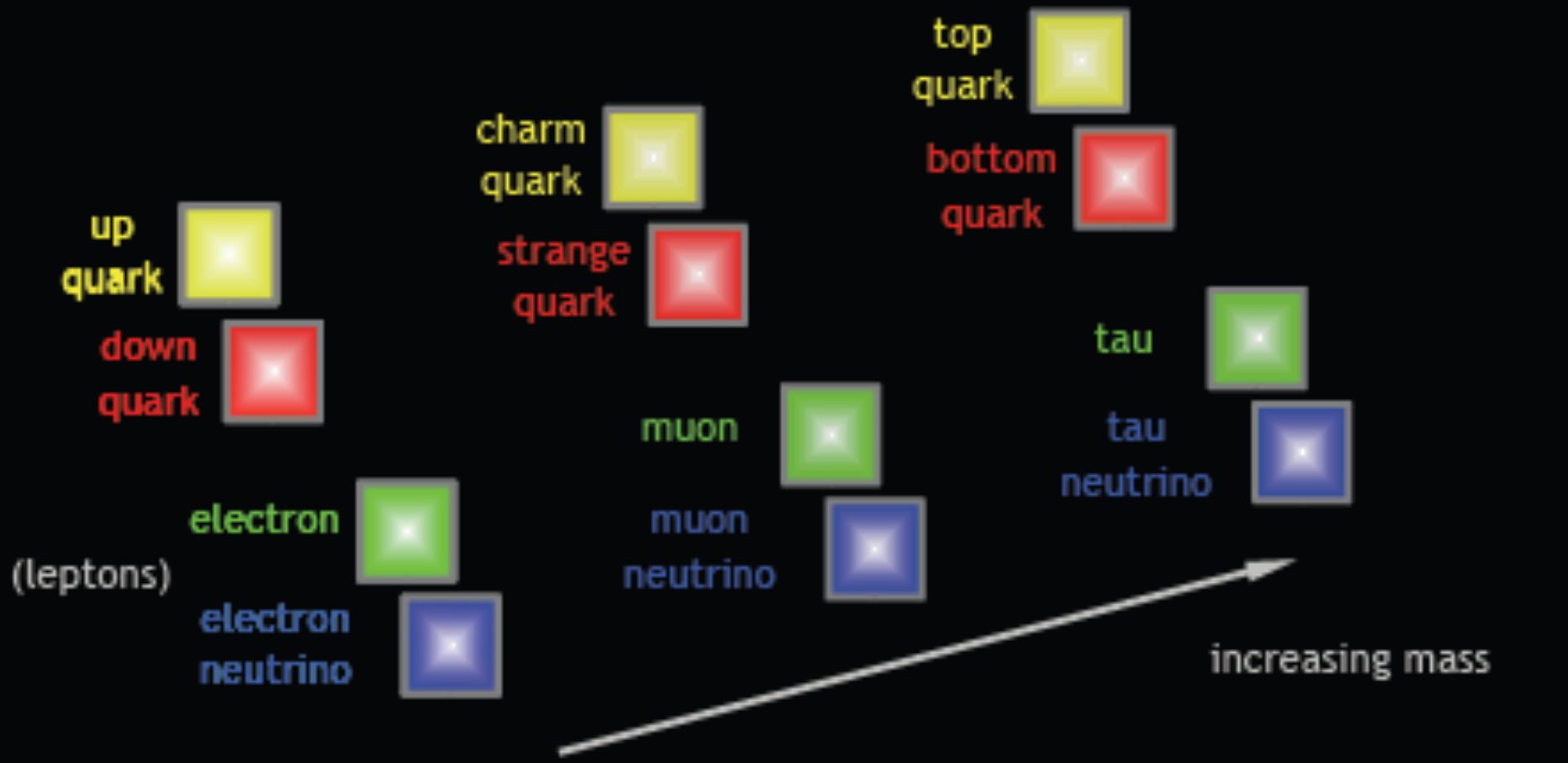
Spherical or Toroidal



Too Simple!



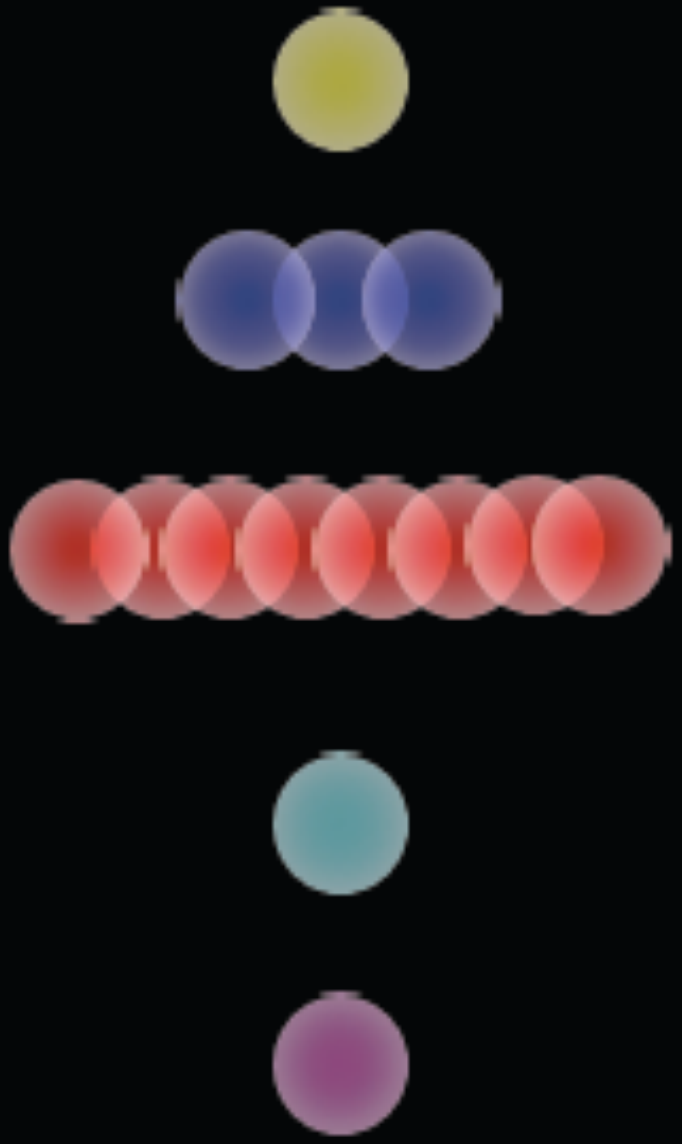
too simple to result in Either the matter particles that exist …



Three generations! "Who ordered that?"

Sean Carroll, From the Universe to the Laboratory, http://pancake.uchicago.edu/~carroll

Or the force carrying particles …



Electromagnetism: the photon

Weak interactions: W & Z bosons

Strong interactions: 8 gluons

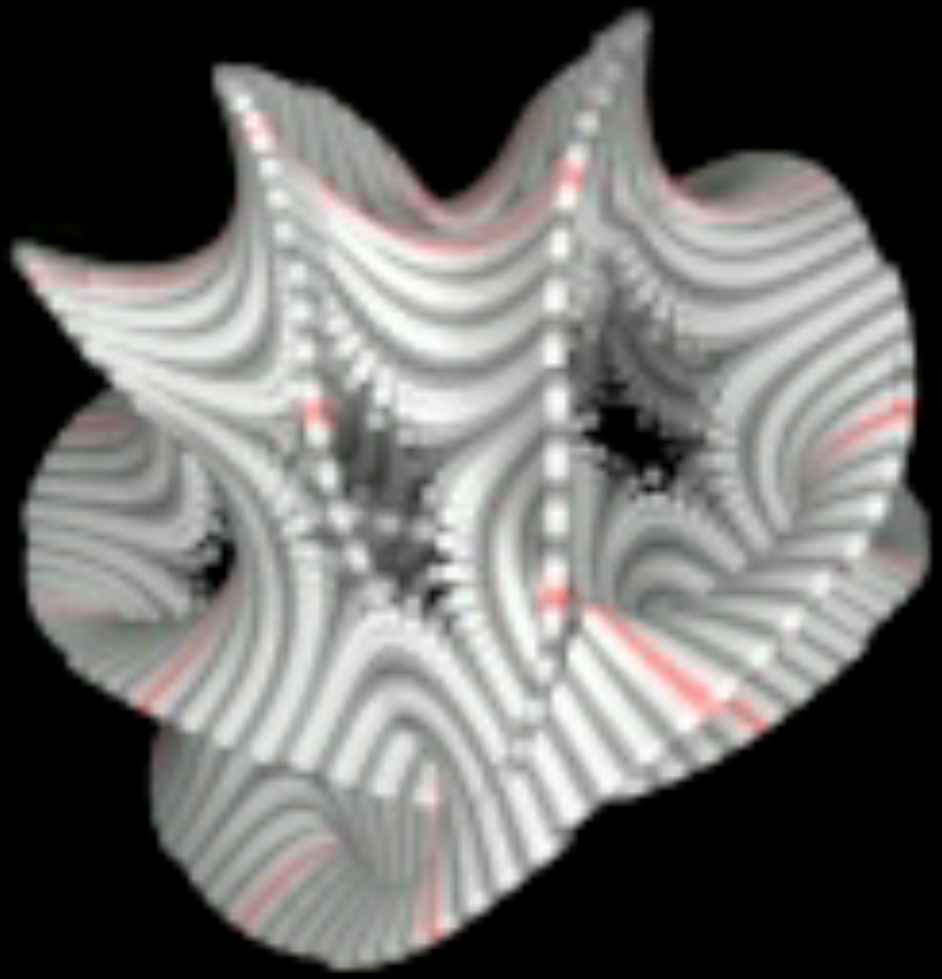
Gravity: the graviton
(not yet quantized!)

Higgs force: the Higgs boson
(not yet detected!)

S. Carroll, http://pancake.uchicago.edu/~carroll

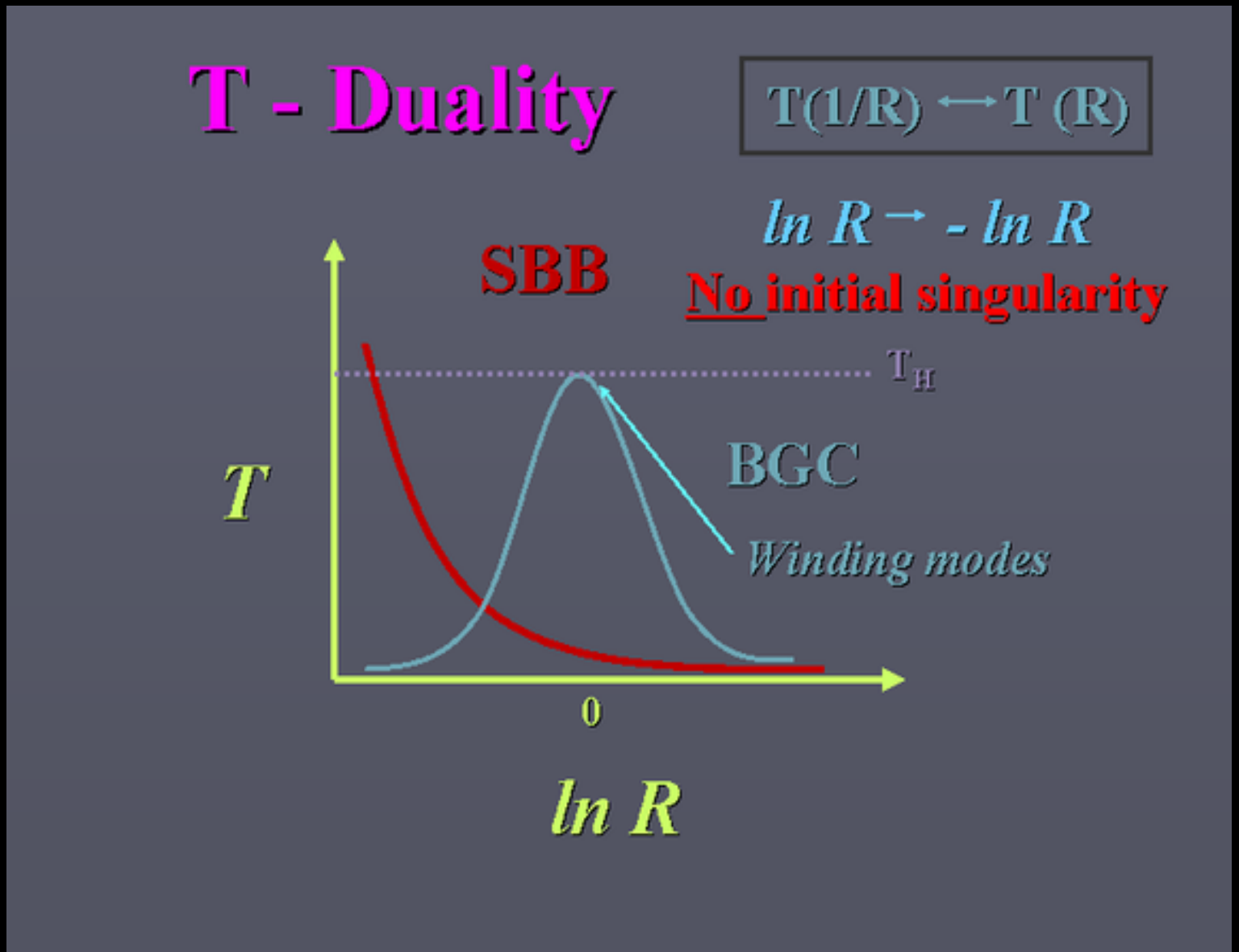
So more complex shapes investigated …

Require Calabi-Yau Compactification Shape from 6 Compactified Dimensions



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

Finite Initial Size and Temperature of String Theory Universe

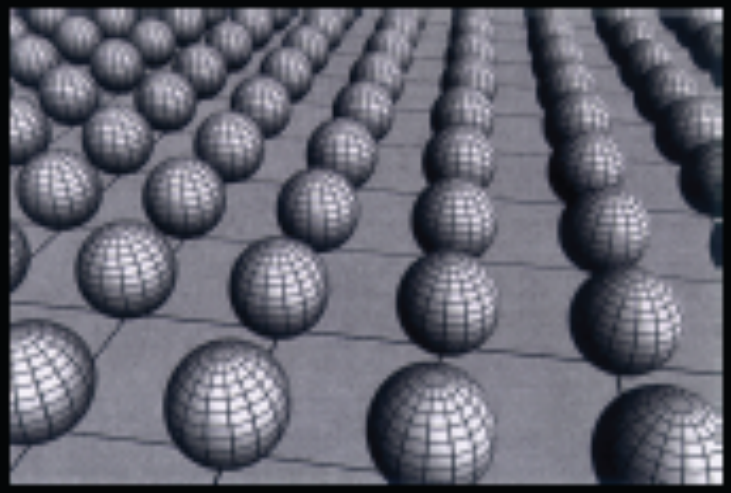


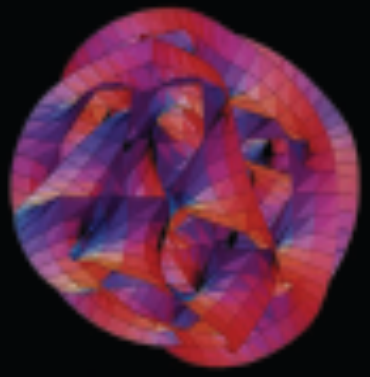
R. Brandenberger

Can extra dimensions help with dark energy? Maybe.

Crucial fact: there's not just one good way to compactify, there are many. Perhaps 10^{500} !

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.





Maybe each compactification actually exists somewhere. Regions outside our observable universe, where the laws of physics and constants of nature appear to be different.

In that case, vacuum energy would be like the weather; not a fundamental parameter, but something that depends on where you are in the universe.

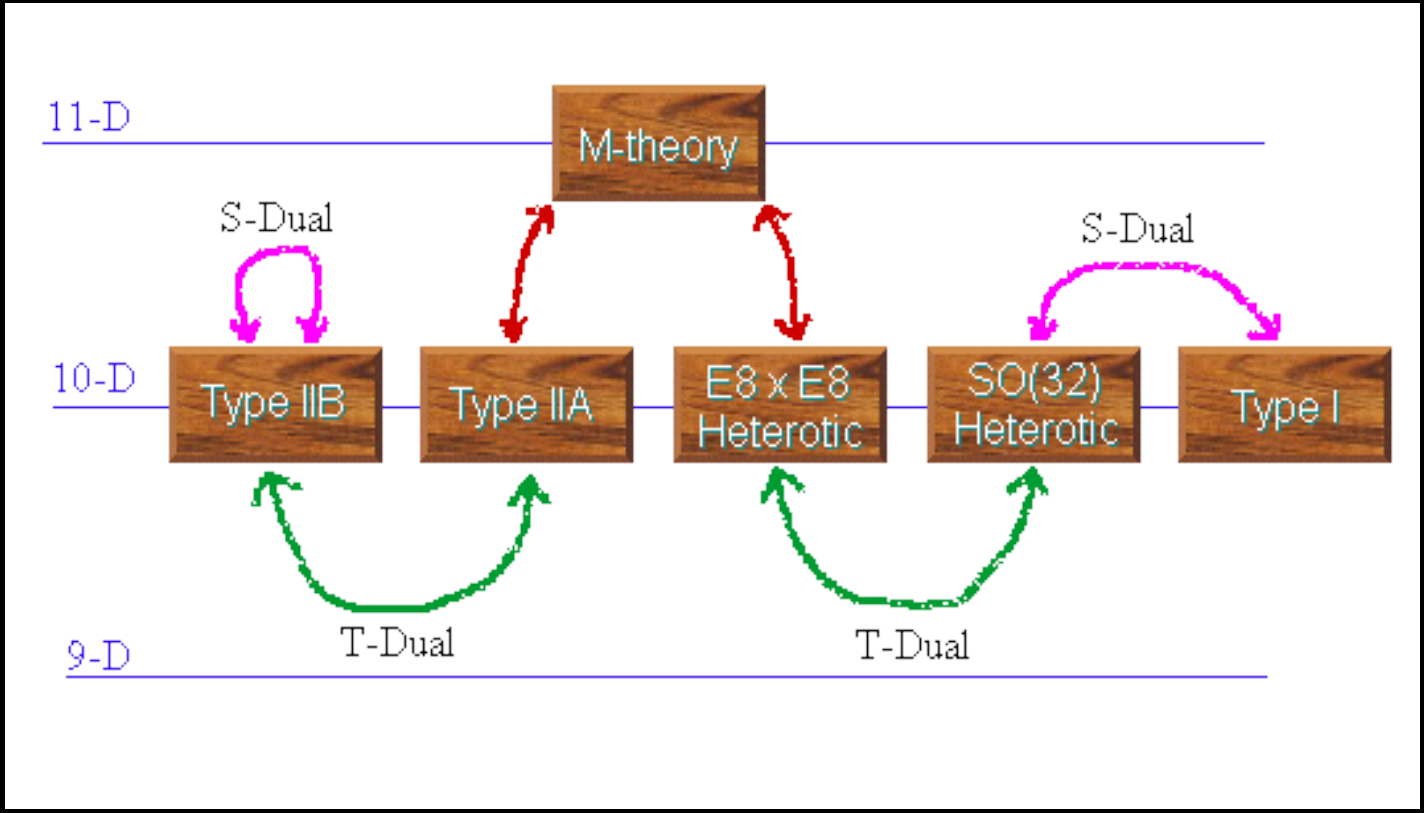
Therefore (so the reasoning goes), it's hardly surprising that we find such a tiny value of the vacuum energy - regions where it is large are inhospitable (like the Sun).

S. Carroll, http://pancake.uchicago.edu/~carroll

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

www.sukidog.com/jpierre/strings/

Solution: Duality (Equality) of All 5 String Theories



www.sukidog.com/jpierre/strings/

Each "Theory" is SAME THEORY IN DIFFERENT MATHEMATICAL LANGUAGE

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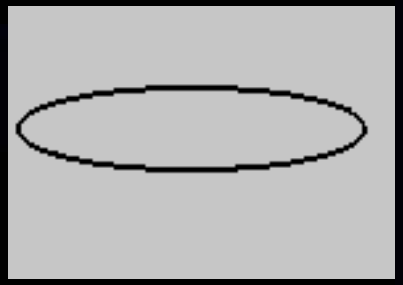
www.sukidog.com/jpierre/strings/

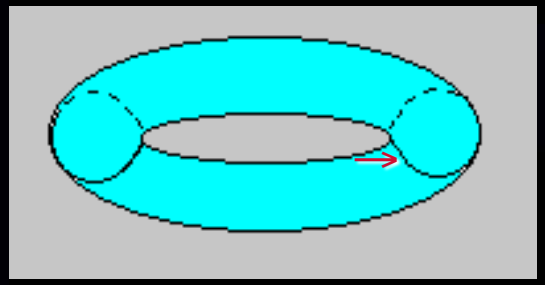
www.sukidog.com/jpierre/strings/

String

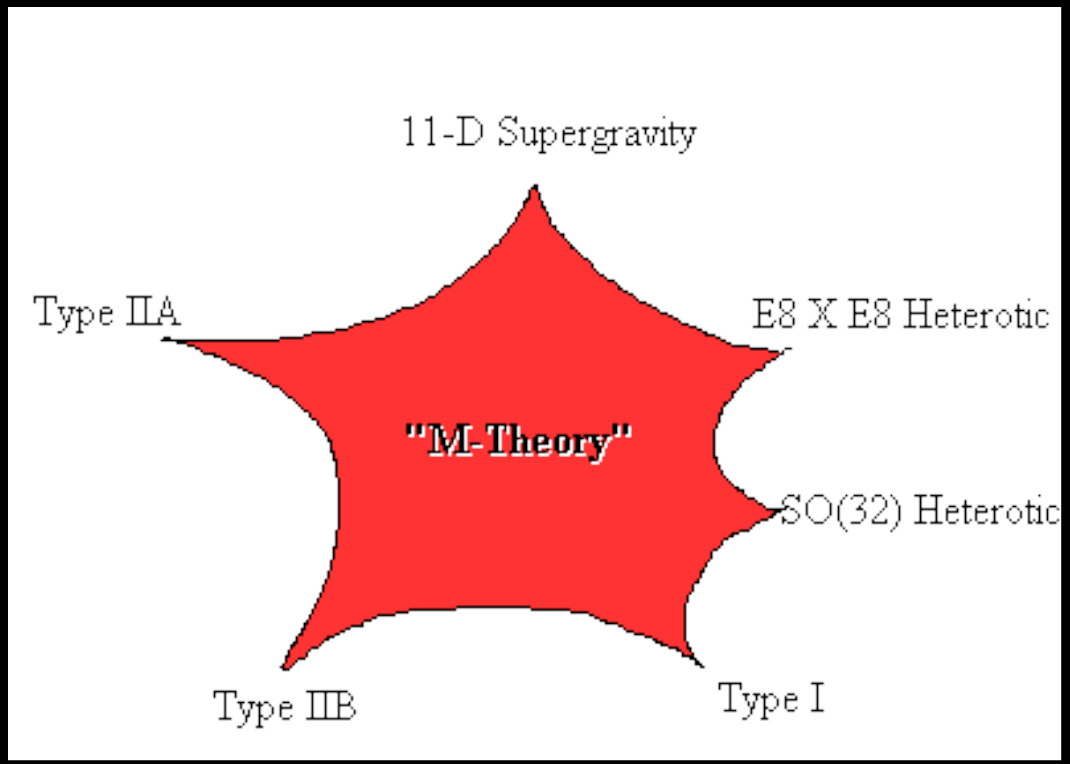


w/ 10 Dim

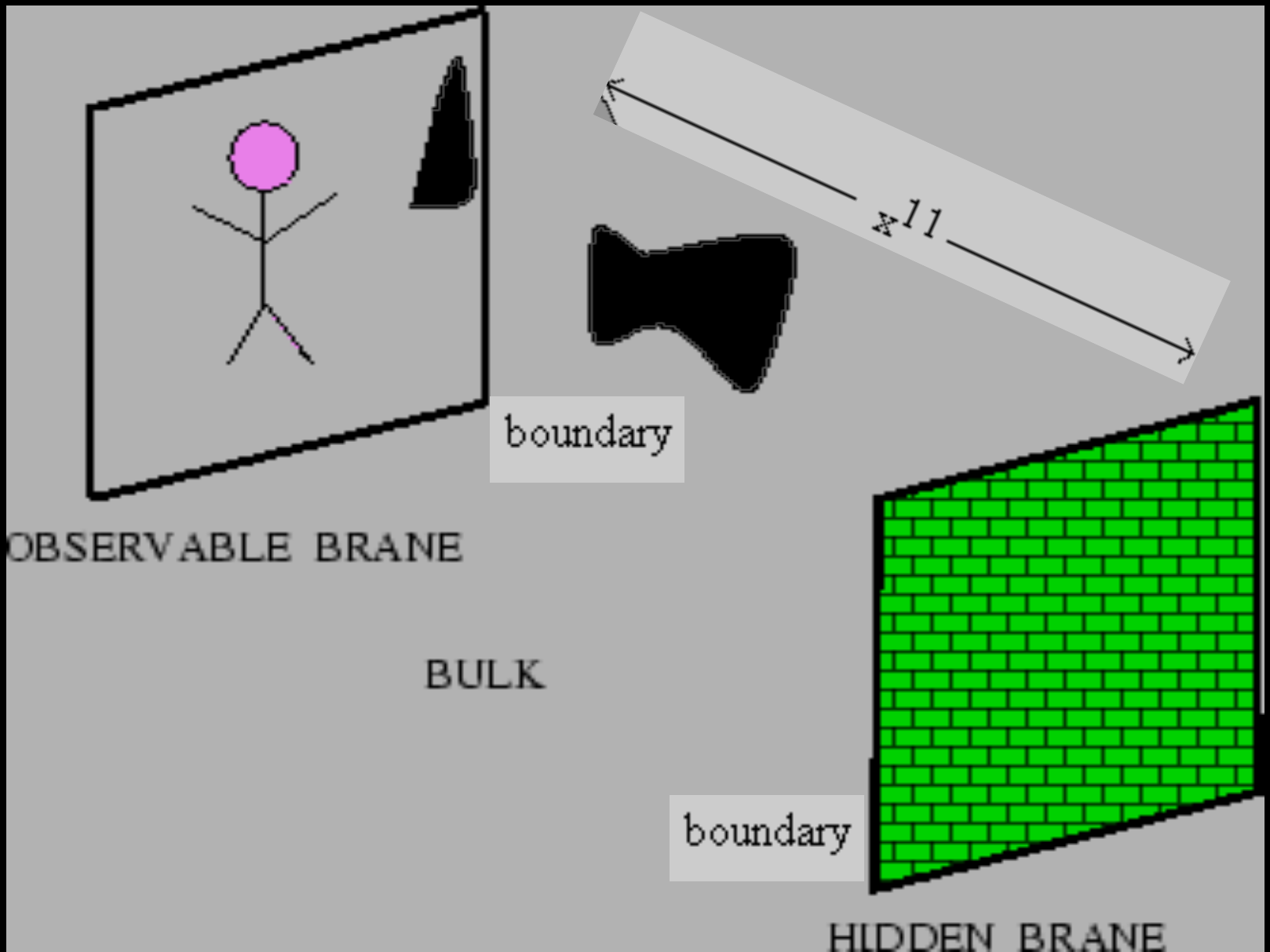
Membrane



w/ 11 Dim



Two 9-brane "Universes" = "Us & Them" and an extra dimension between



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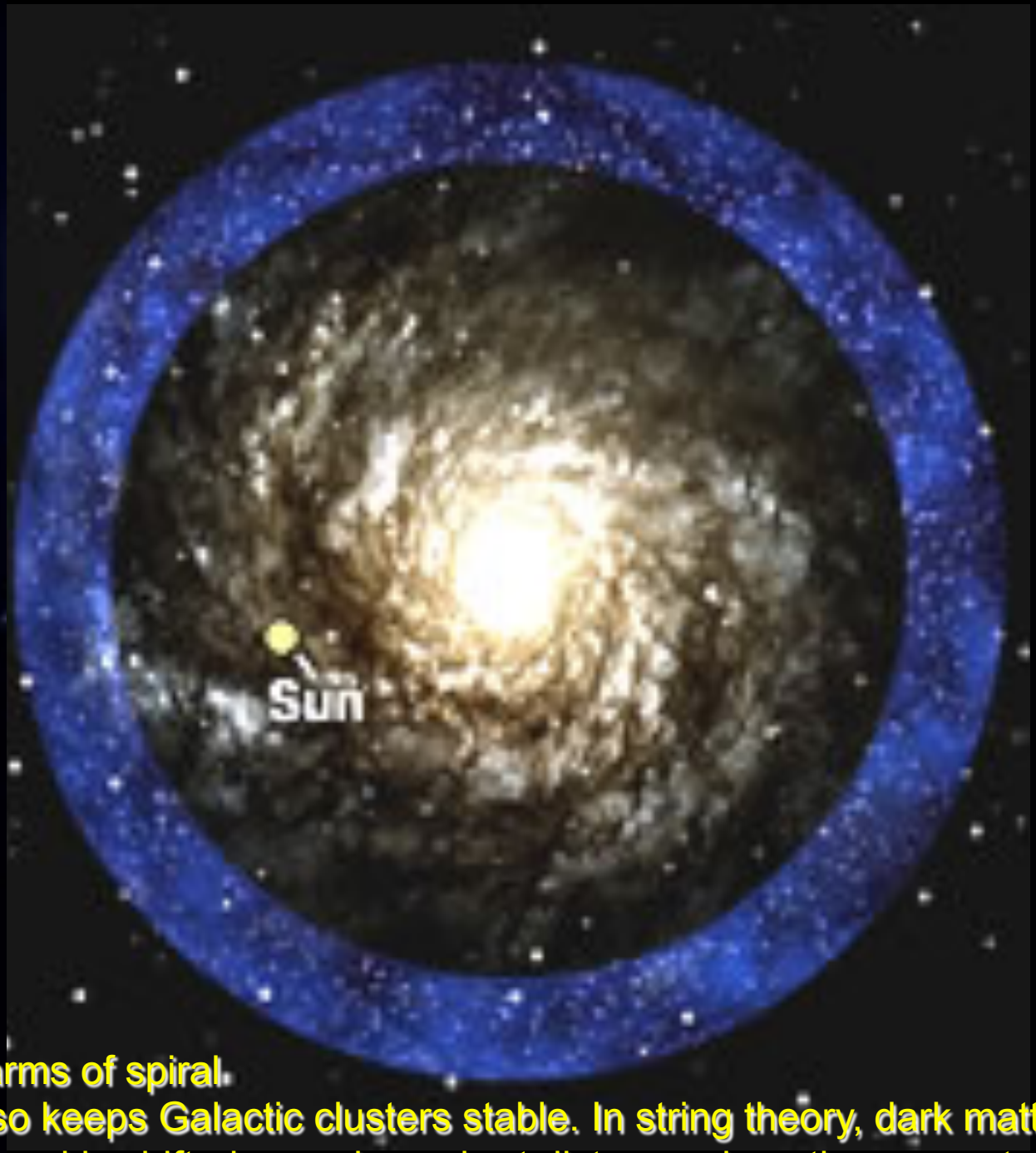
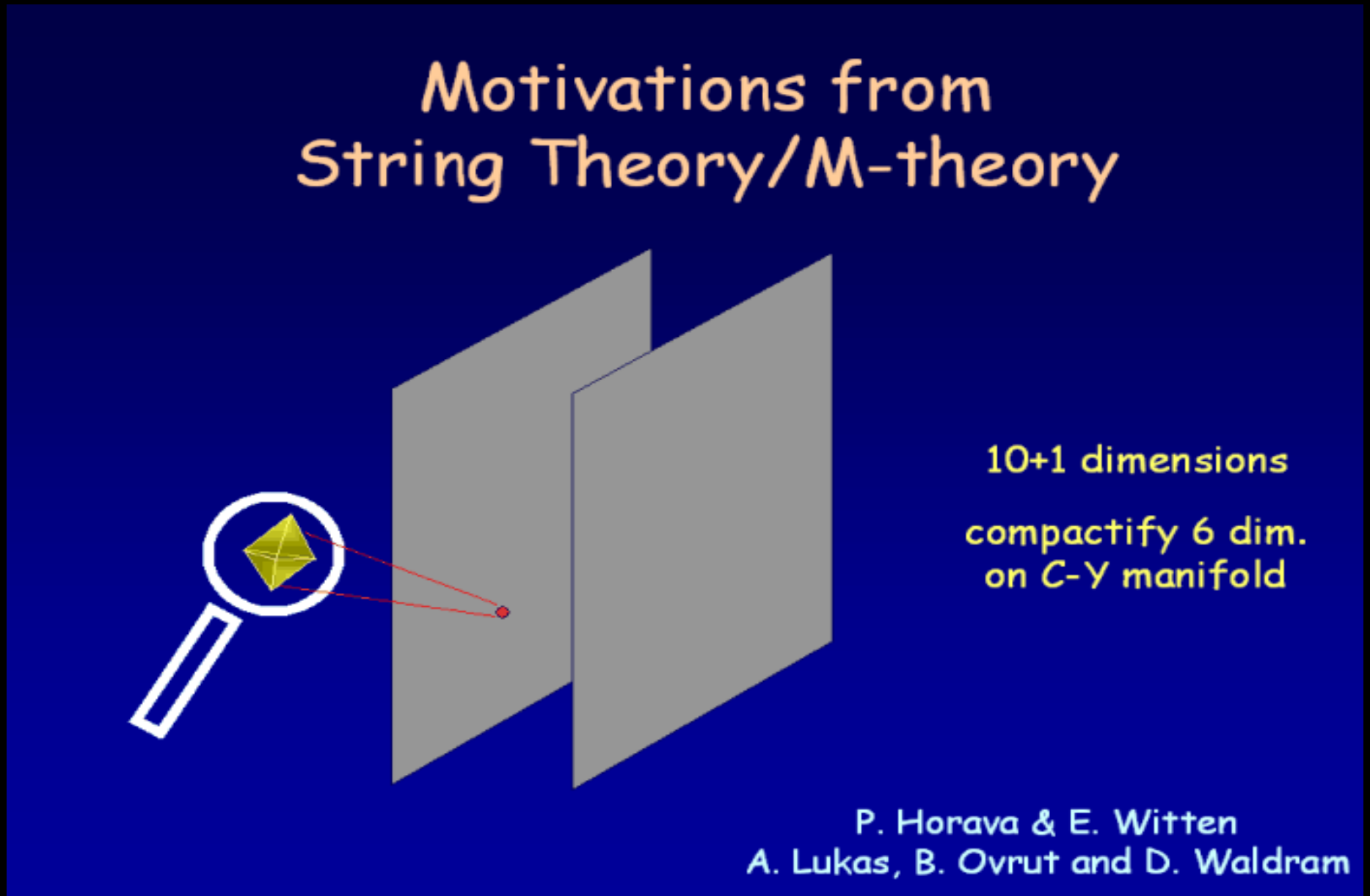
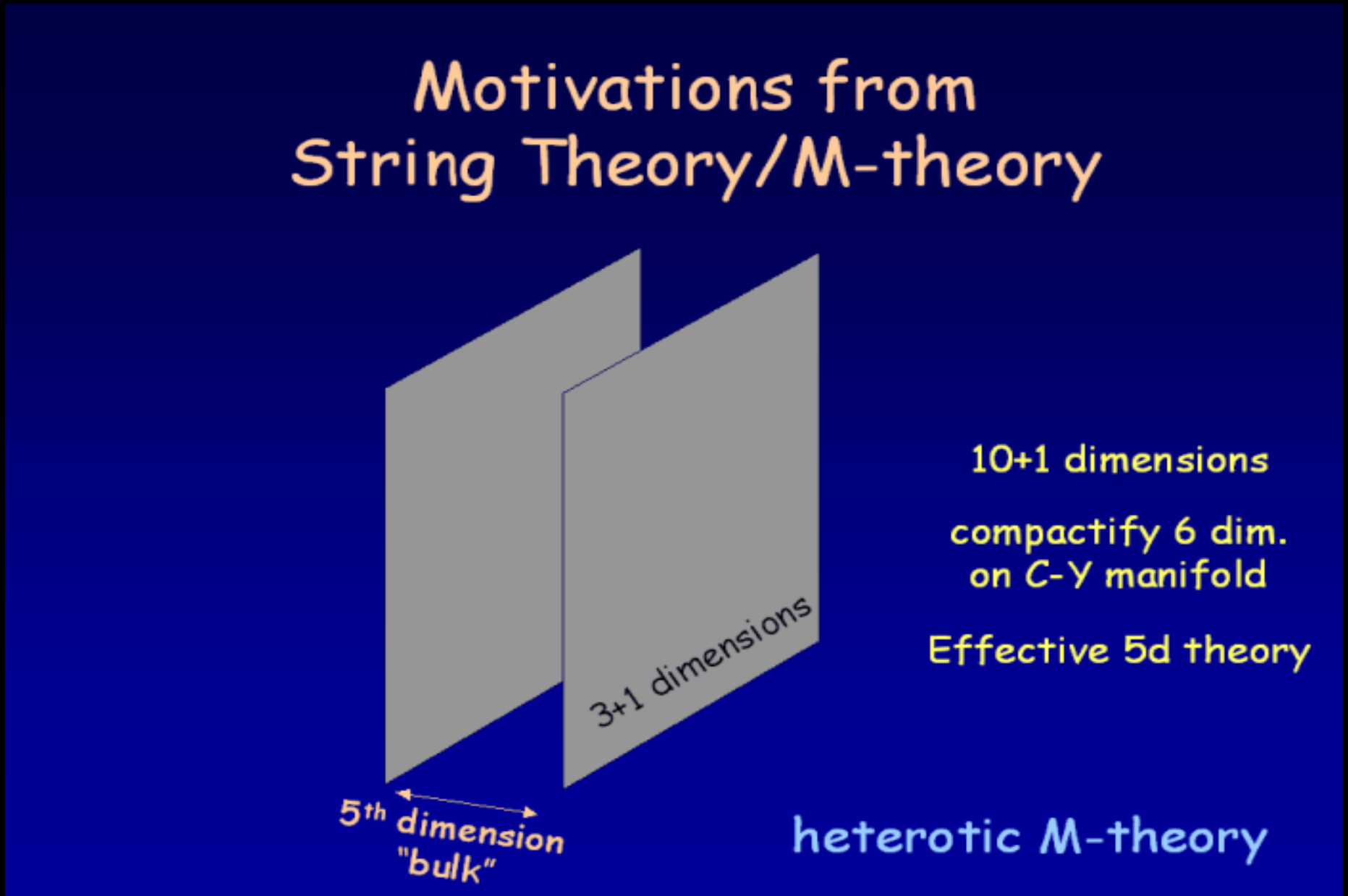


Dark Matter keeps arms of spiral galaxies stable & also keeps Galactic clusters stable. In string theory, dark matter is the matter in the hidden universe and is shifted away by a short distance along the new extra direction.

Compactify 6 of the 9 Spatial Directions of each Brane as Before

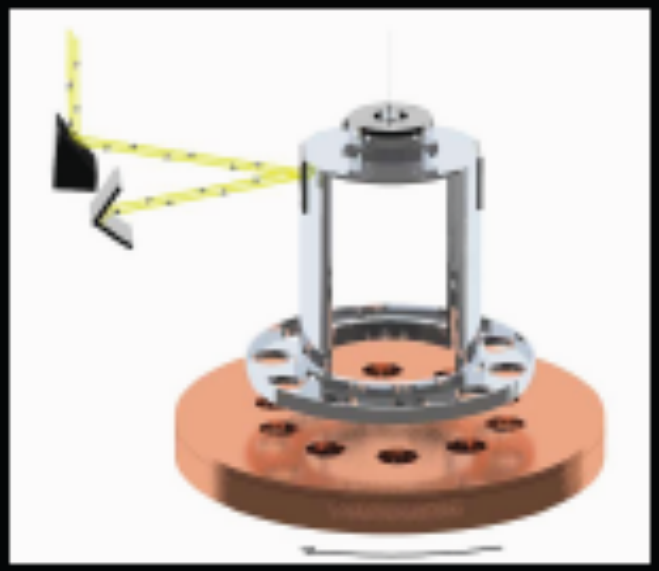


Effective 5-Dimensional Theory



Tests for sub-mm.directions

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

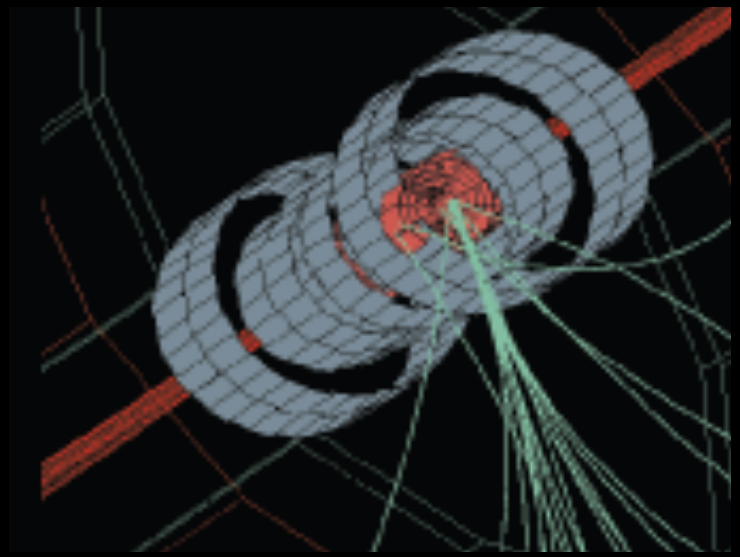


If gravity leaks into extra dimensions, Newton's inverse-square law should break down at small distances - gravity will be stronger than you think.

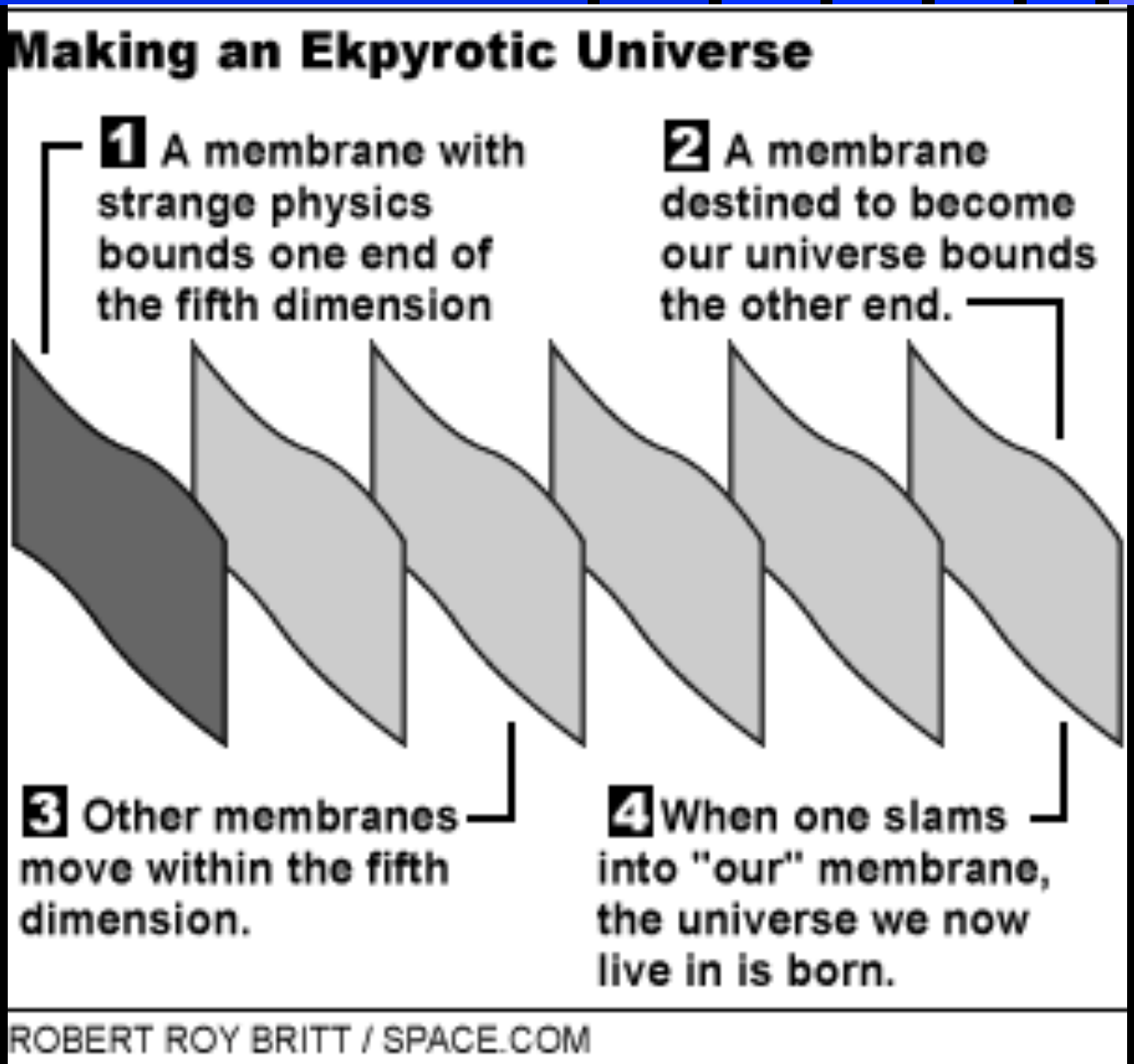
Standard gravity verified down to 0.15 mm at Univ. of Wash. with 97% confidence level

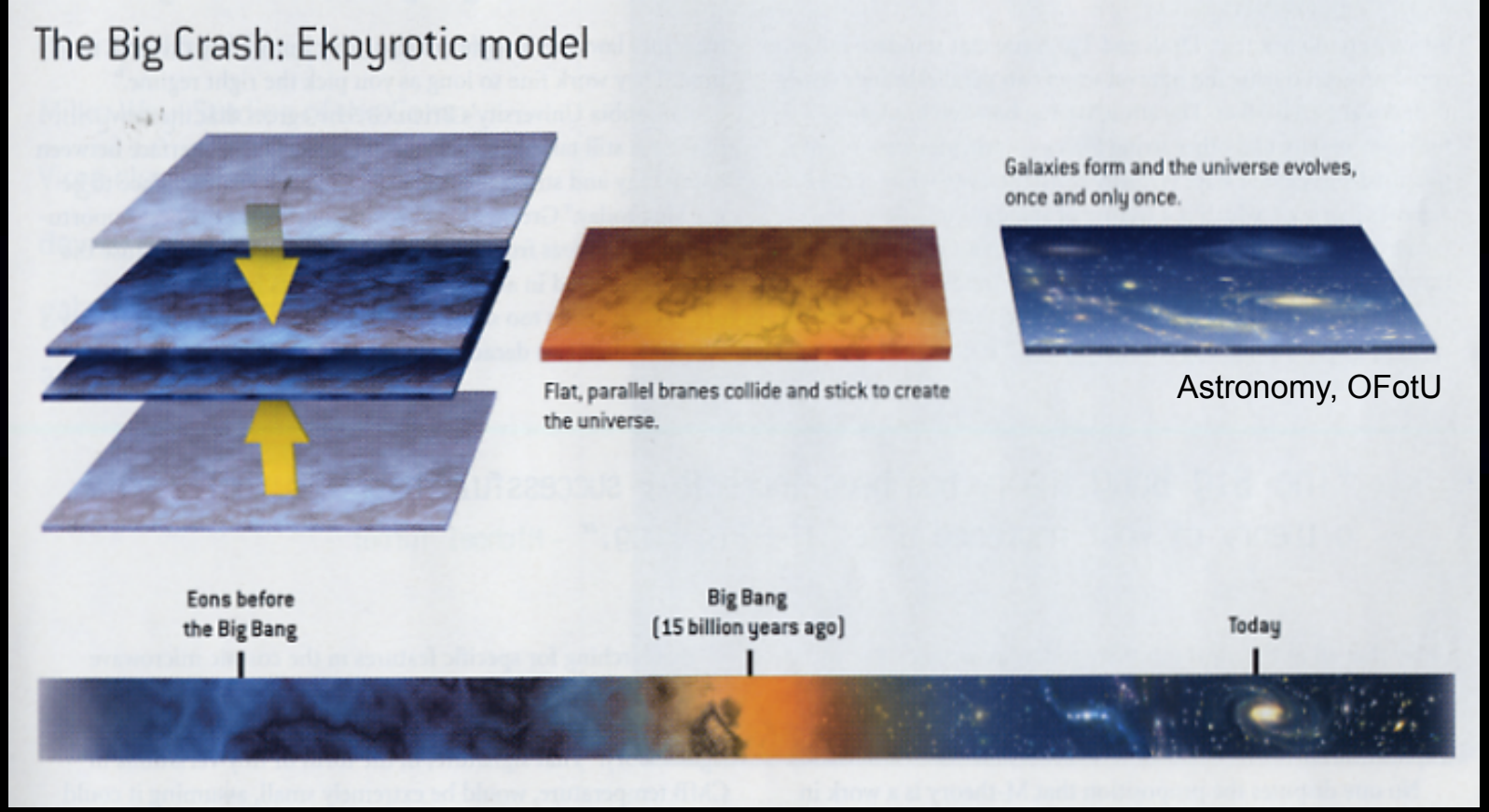
Manufacturing of Stringy Blackholes!

- If sub-mm. dimension then it may be possible to produce gravitons and mini-black holes (with peco-second half-lives) at Fermilab & CERN this decade!
- Mini-black holes have distinct decays —easily identifiable!
- Black Holes Detectors for Fermilab and CERN



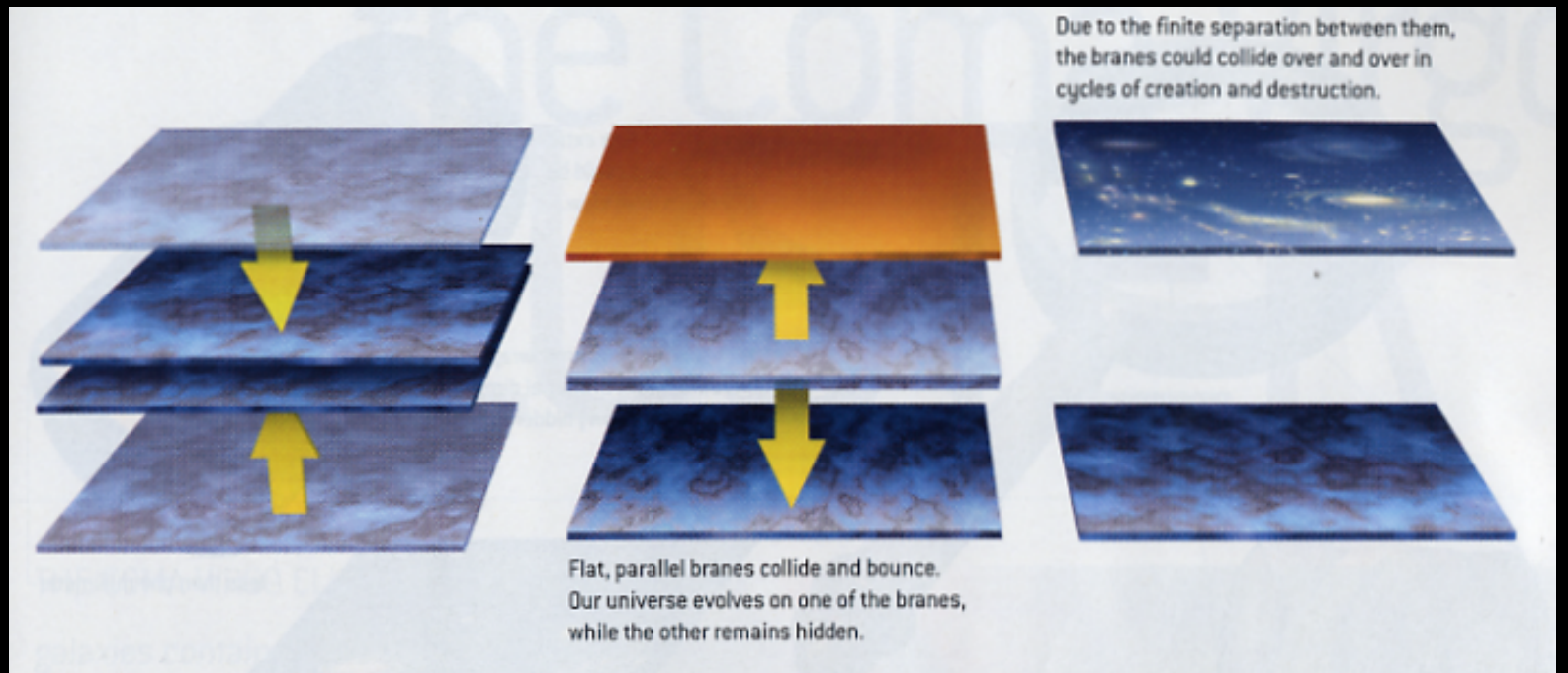
Proposed Explanation for Big Bang Implying Time Before Time!





Single Event

Astronomy, OFotU



Cyclical Events

Astronomy, OFotU

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, separated, Big Bang regions might have been formed from distinct collision points of Branes!

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

Maybe each compactification actually exists somewhere. Regions outside our observable universe, where the laws of physics and constants of nature appear to be different.

In that case, vacuum energy would be like the weather; not a fundamental parameter, but something that depends on where you are in the universe.

Therefore (so the reasoning goes), it's hardly surprising that we find such a tiny value of the vacuum energy - regions where it is large are inhospitable (like the Sun).

S. Carroll, http://pancake.uchicago.edu/~carroll

String Landscape

~ 10^{12} x 10^{500} Models in M-Theory

String/M Landscape

C.C./D.E. $(M_{Pl})^4$

1

de Sitter

0

10^{-120}

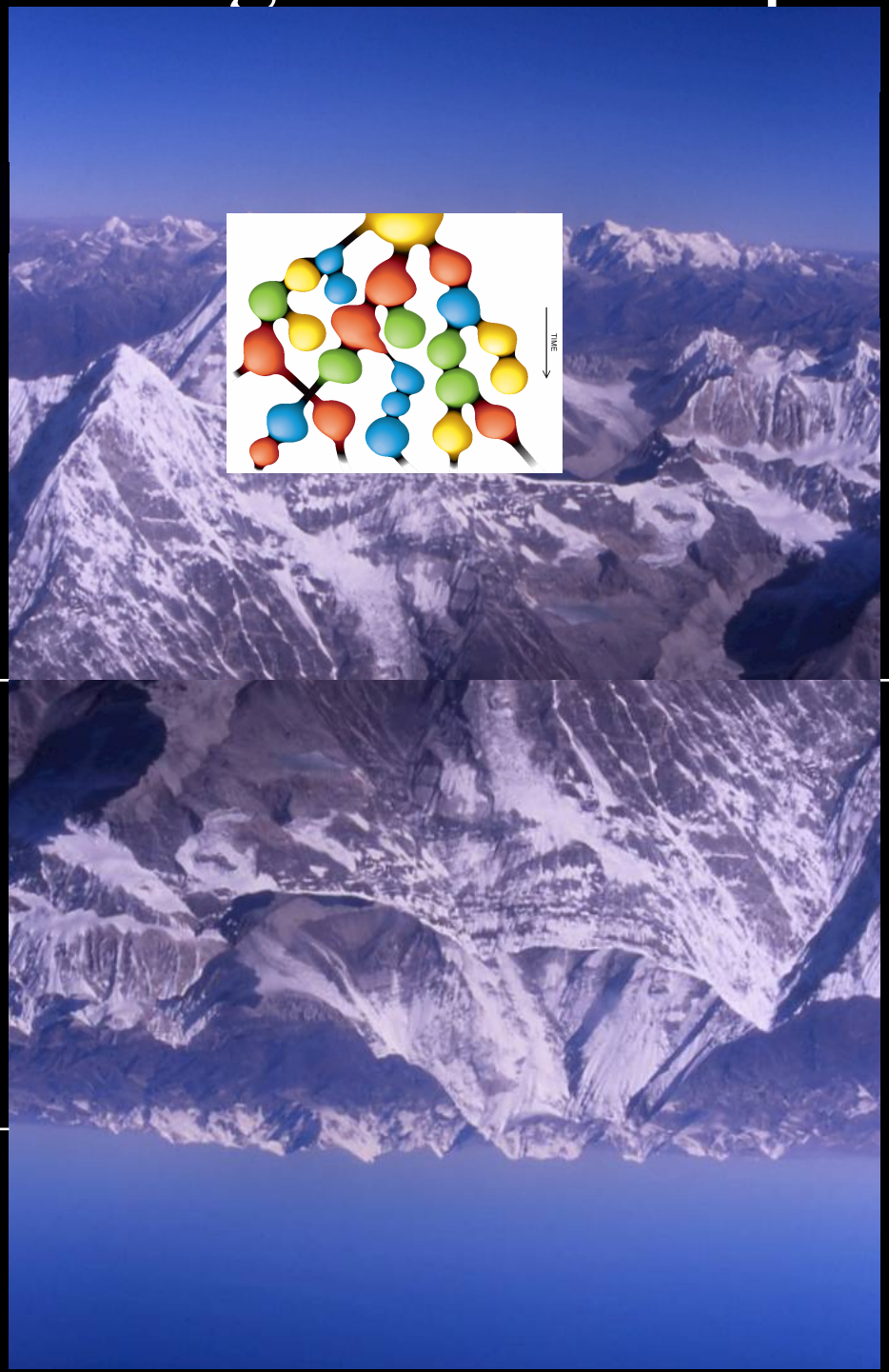
Our universe

Anti-de Sitter

-1

String/M Landscape

C.C./D.E. $(M_{Pl})^4$



1

de Sitter

0

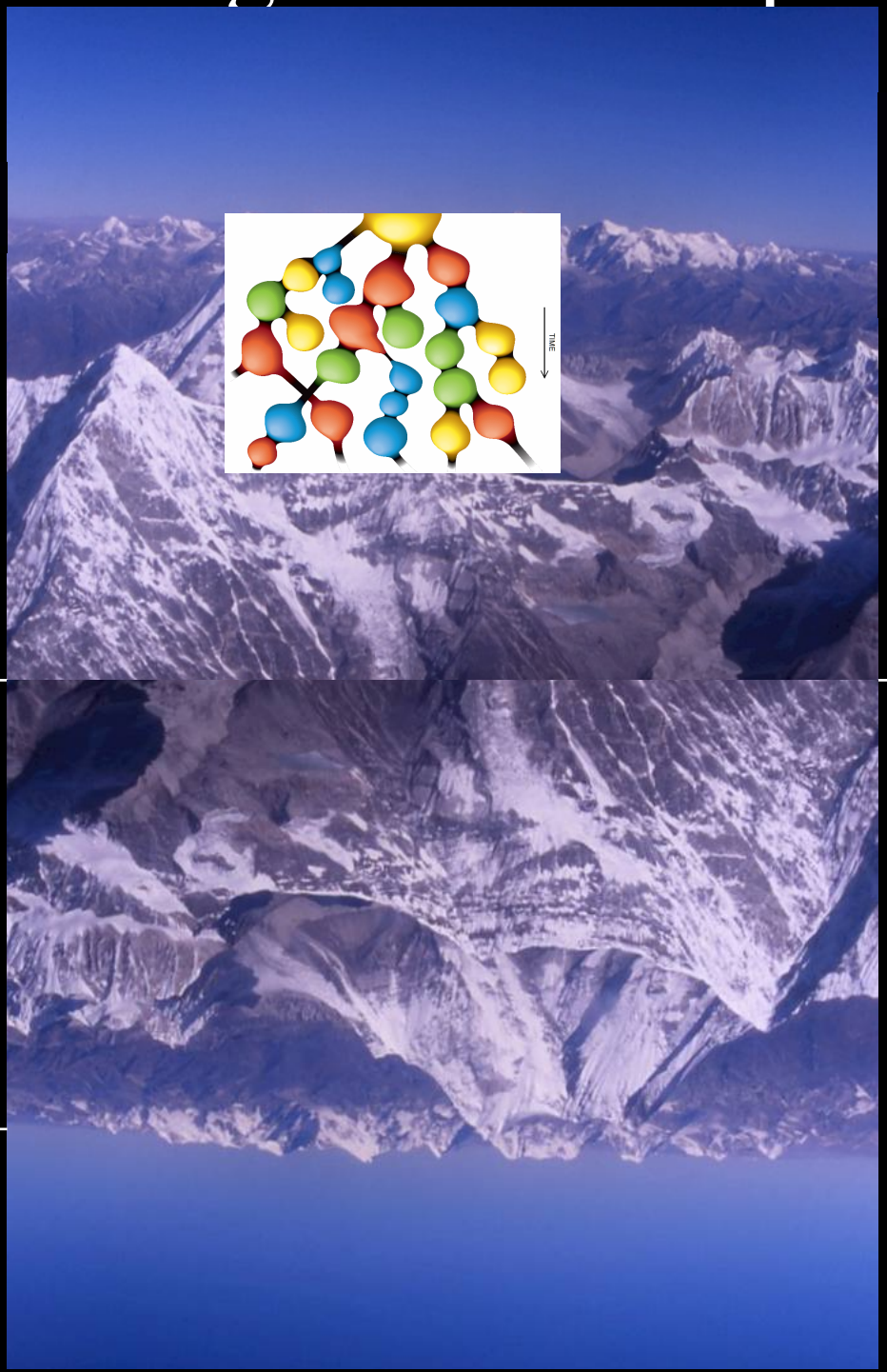
10^{-120}
Our universe

Anti-de Sitter

-1

String/M Landscape

C.C./D.E. $(M_{Pl})^4$



1

de Sitter

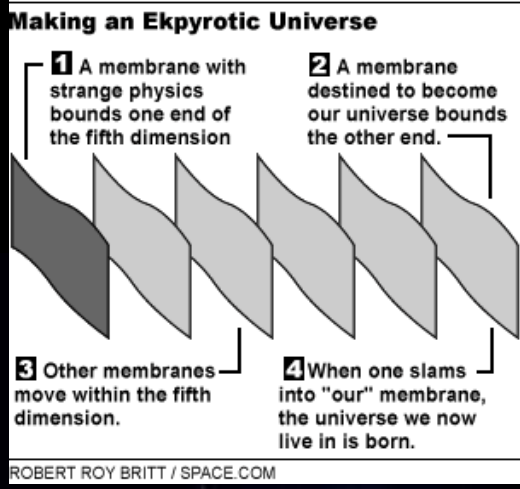
0

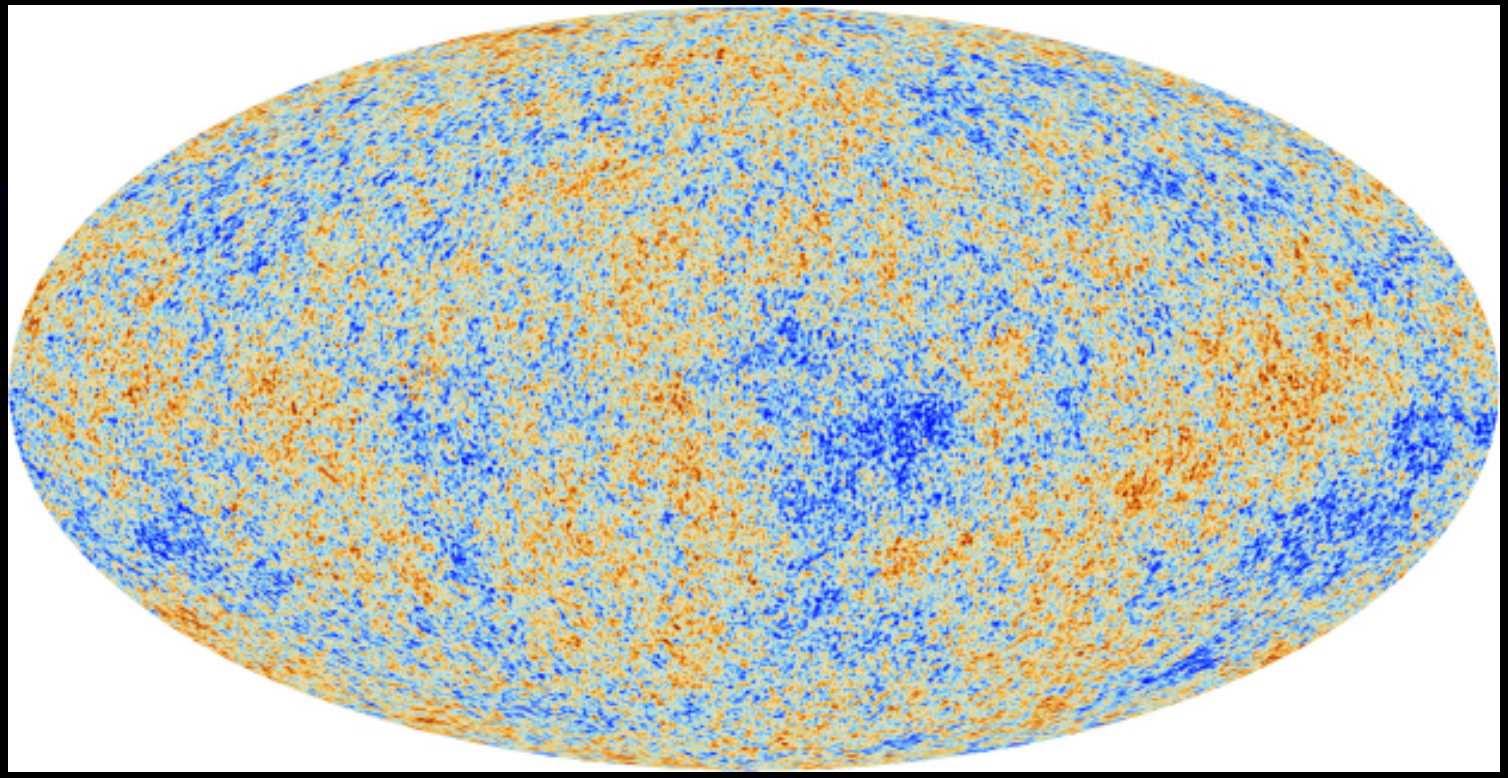
Anti-de Sitter

-1

10^{-120}

Our universe





The extraordinary quality of the Planck data reveals the presence of subtle anomalies in the CMB pattern that might challenge the very foundations of cosmology. The most serious anomaly is a deficit in the signal at large angular scales on the sky, which is about ten per cent weaker than the standard model would like it to be. Other anomalous traits that had been hinted at in the past - a significant discrepancy of the CMB signal as observed in the two opposite hemispheres of the sky and an abnormally large 'cold spot' - are confirmed with high confidence. Planck's new image of the CMB suggests that some aspects of the standard model of cosmology may need a rethink, raising the possibility that the fabric of the cosmos, on the largest scales of the observable Universe, might be more complex than we think. (ESA Report)

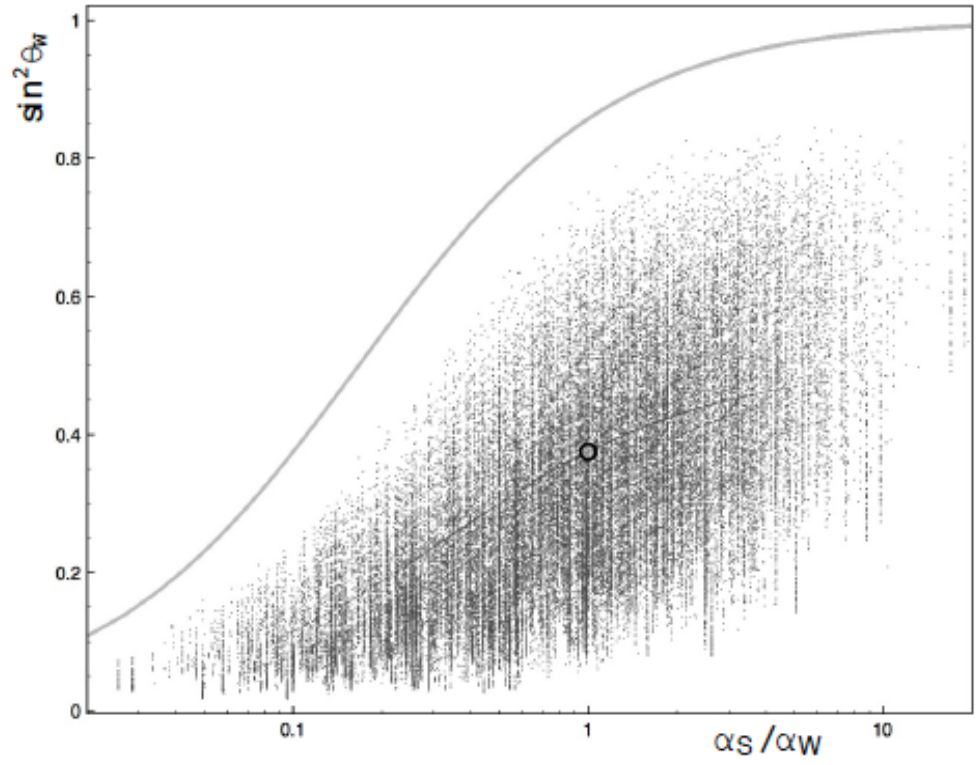


FIG. 3 Distribution of Standard Model Couplings in a class of intersecting brane models.

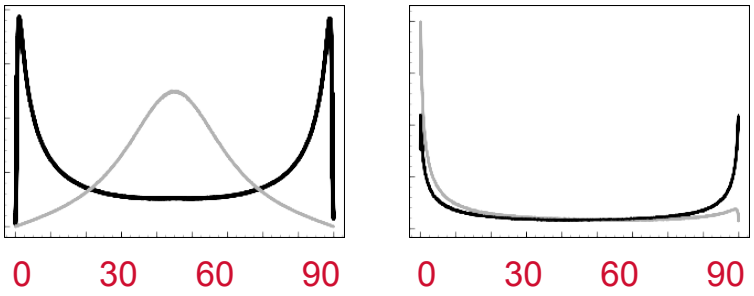


FIG. 4 Distribution of CKM angles at small and large angles for a scale invariant distribution. The black line is for θ_{12} and θ_{23}, the gray line is for θ_{13}.

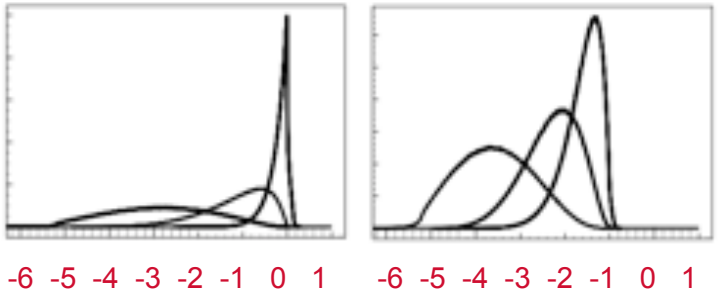


FIG. 5 Distribution of up-type (u,c,t) and down-type (d,s,b) masses. On the horizontal axis powers of ten are indicated.

A.N. Schellekens, 'Life at the Interface of Particle Physics and String Theory, arXiv:1306.5083v2.

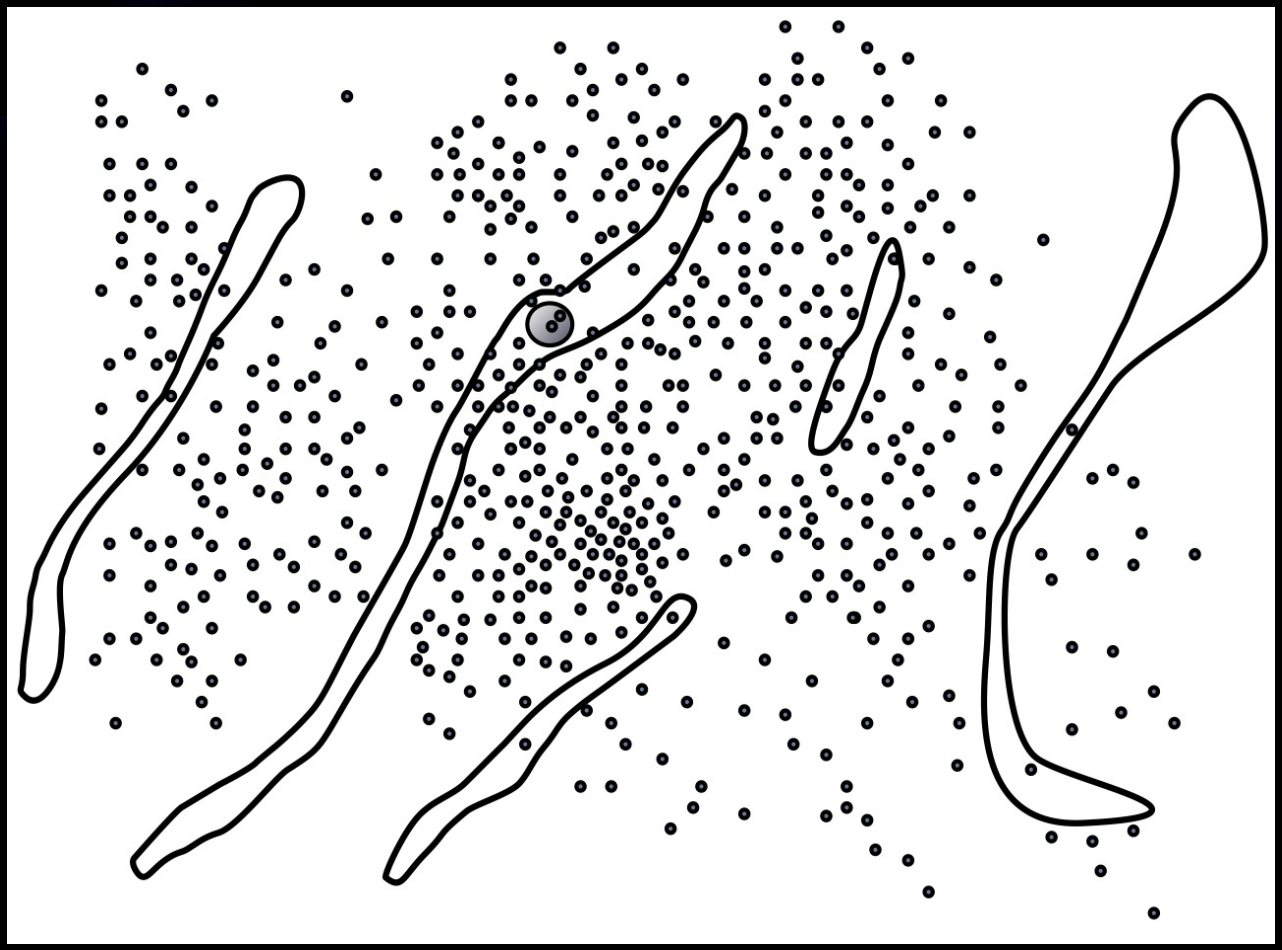


FIG. 1 Habitable regions in QFT space. The gray circle represents the experimental bounds on the Standard Model. The dots show the distribution of QFT points in a hypothetical landscape.
A.N. Schellekens, 'Life at the Interface of Particle Physics and String Theory, arXiv:1306.5083v2.

The String Landscape and the Multiverse

- The Multivercentric Picture—is it the next step in our perception of reality? (And what might come after?)

- It would provide a much deeper understanding of a reality vastly (unimaginably) beyond our universe.

Baylor University
PHYSICS

String Landscape and the Multiverse

- Next step in our perception of reality?
  Multivercentric Picture!
- May provide a much deeper understanding reality—beyond our universe,