

Cosmology in the Multiverse

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Outline

Cosmology and Big Questions

Cosmology as precision science

Cosmology in the Multiverse

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Some of the Big Questions...

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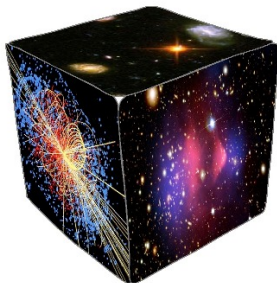
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These questions are addressed (not necessarily answered) by particle physics and cosmology



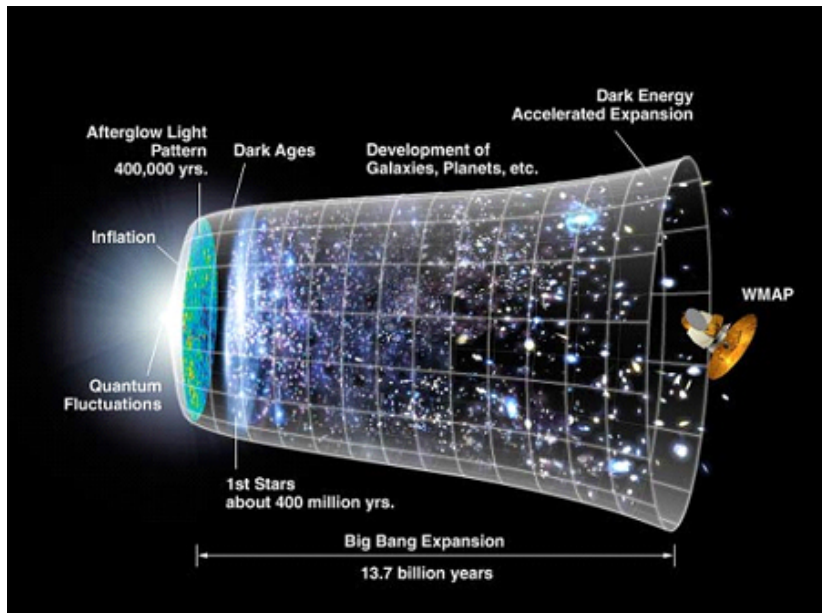
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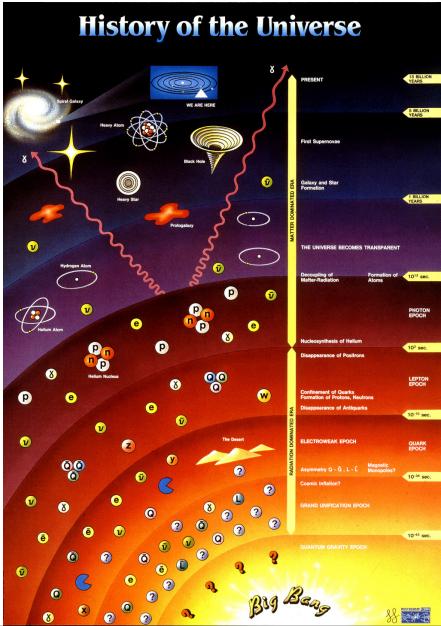
Cosmology in the Multiverse

Sketch of our Universe



History of the Universe

All started with the Big Bang...
Empirical facts:

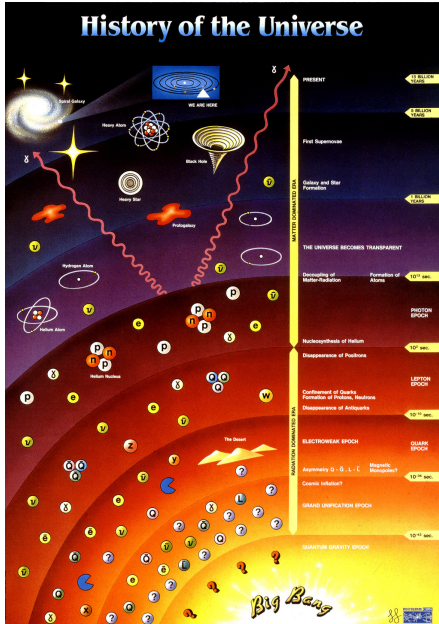


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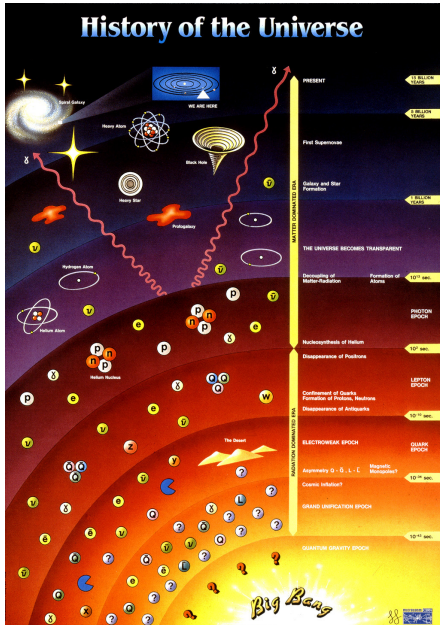


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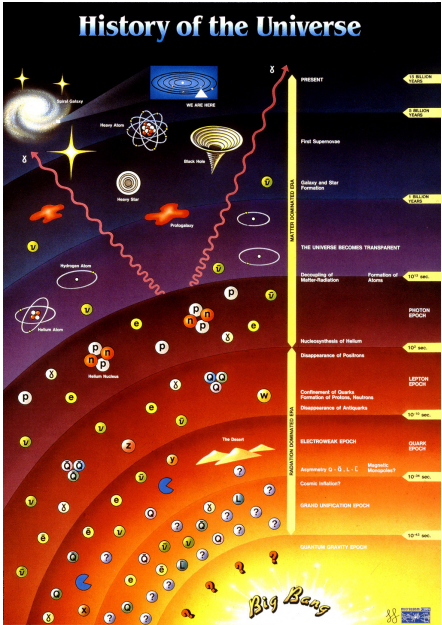


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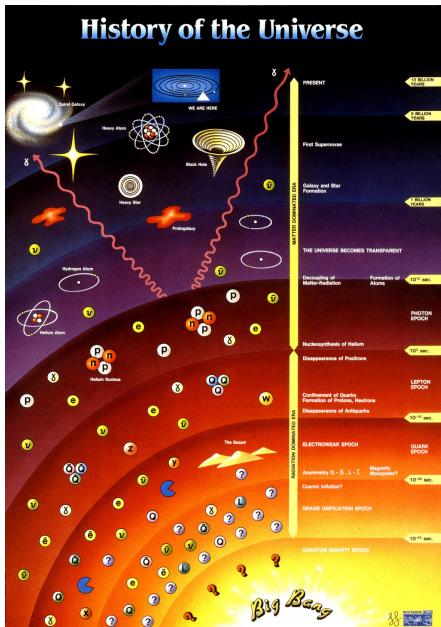
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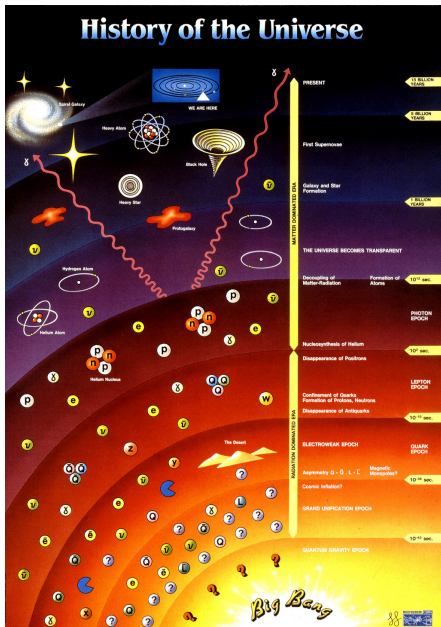


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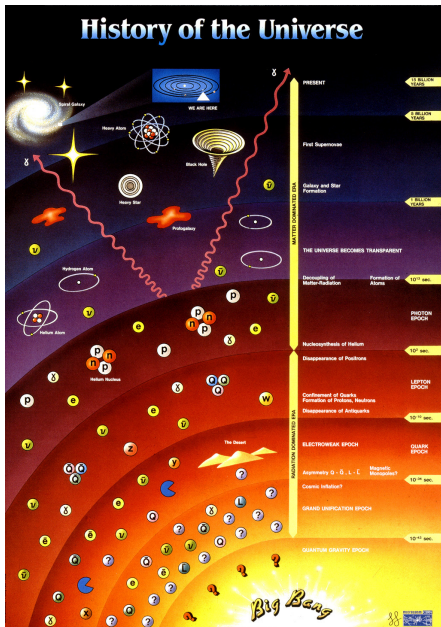


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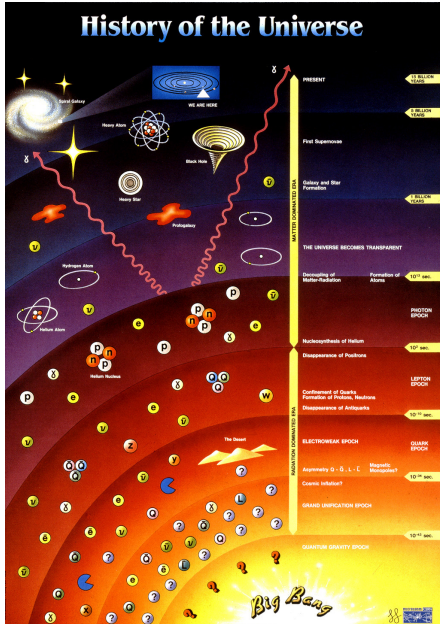
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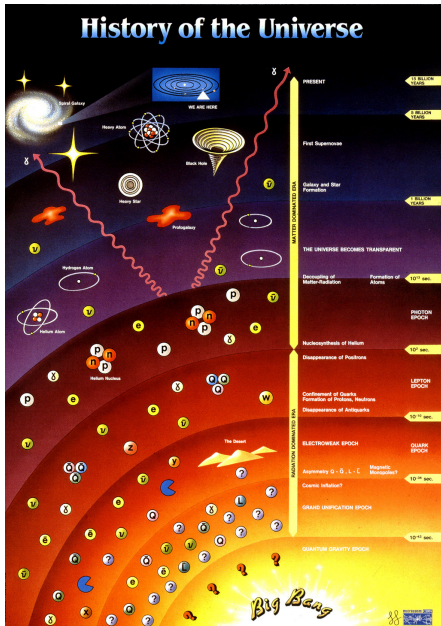
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Big Bang experimentally verified

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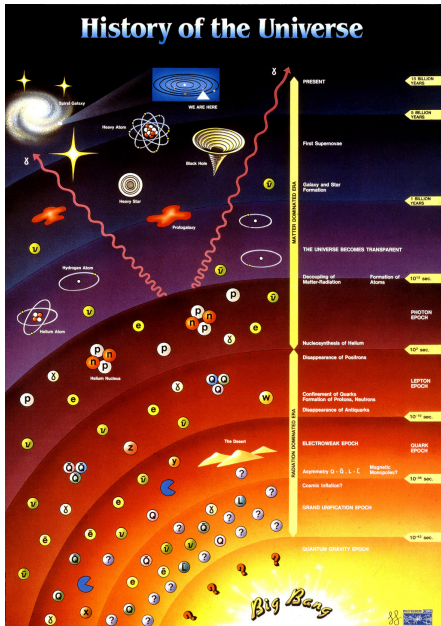
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Inflation:

- ▶ Early Universe inflates exponentially (10^{26} -fold growth)

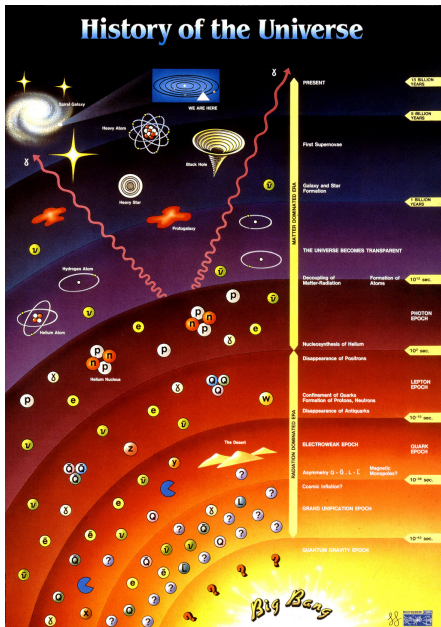
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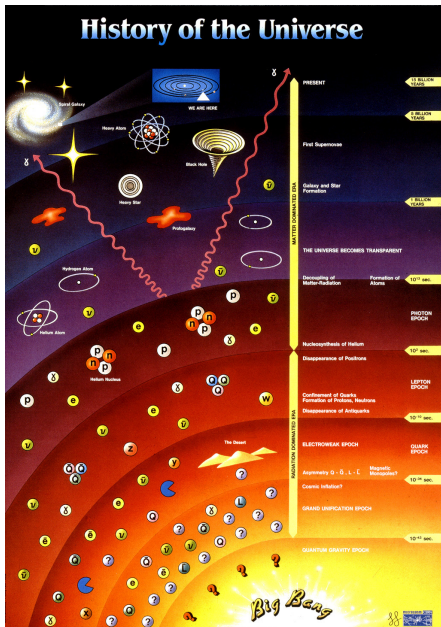
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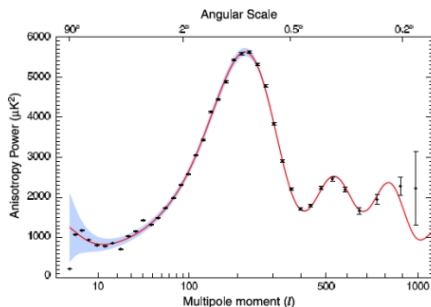
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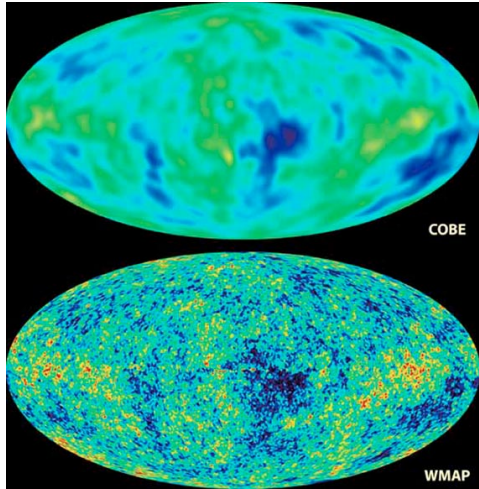
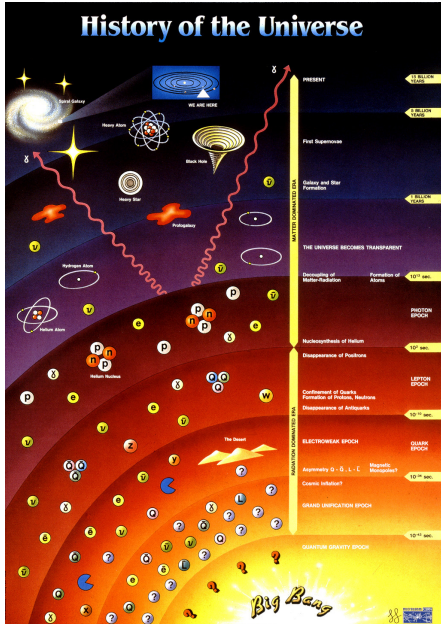
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From the WMAP data (2008)

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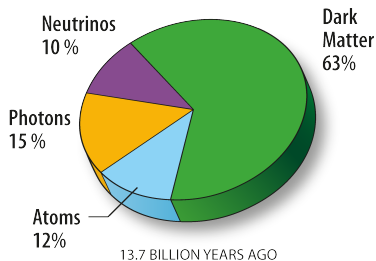
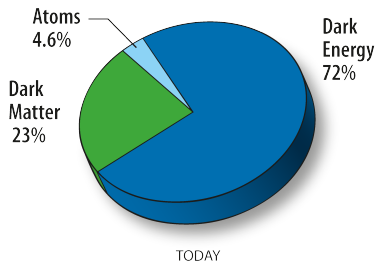


COBE data (20 years ago, upper fig.)
 WMAP data (6 years ago, lower fig.)

Energy budget of the Universe and open questions

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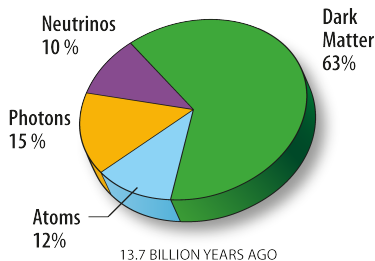
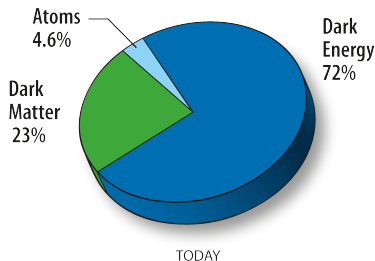
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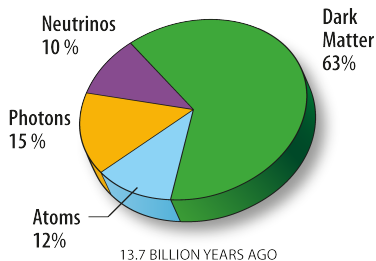
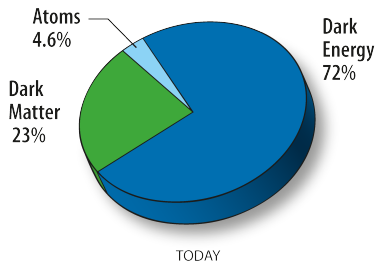
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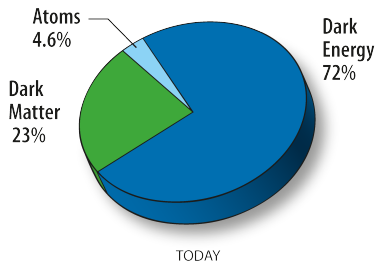
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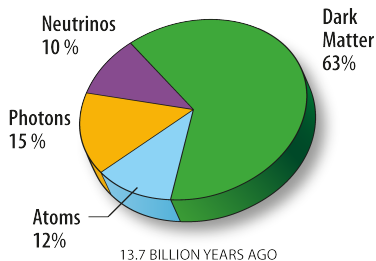


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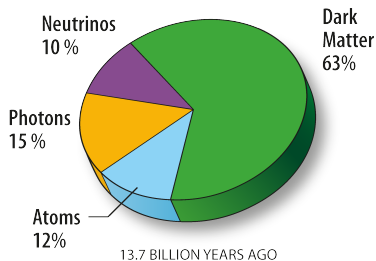
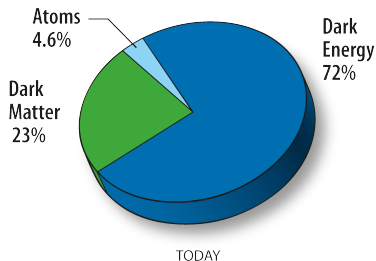


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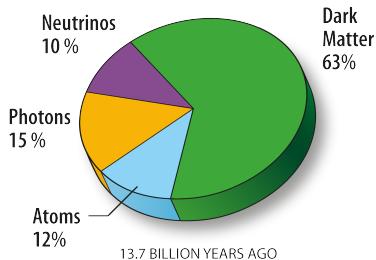
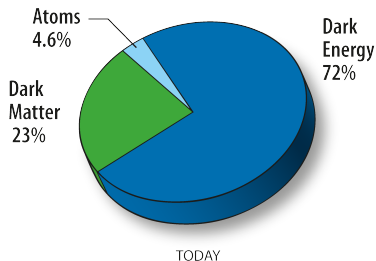
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Currently only one theoretical way to “explain” smallness of cosmological constant: Weinberg’s anthropic argument

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Perhaps we cannot predict everything...

Example: Titius–Bode “law” for semi-major axes of planets probably just coincidence

Scientific arena for the Multiverse

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String theory suggests legitimacy of anthropic reasoning a la Weinberg

Multiverse idea led to strong emotional reactions and “Landskepticism”

Christoph Schönborn, Cardinal Archbishop of Vienna:

“Now, at the beginning of the 21st century, faced with scientific claims like neo-Darwinism and the multiverse hypothesis in cosmology invented to avoid the overwhelming evidence for purpose and design found in modern science, the Catholic Church will again defend human nature by proclaiming that the immanent design evident in nature is real. Scientific theories that try to explain away the appearance of design as the result of chance and necessity are not scientific at all, but, as John Paul put it, an abdication of human intelligence.”

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Well-known physicist on anthropic reasoning, about a decade ago:

“I hate it and it doesn’t make sense.”

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Same physicist, about three years ago:

“I hate it.”

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Peter Woit, notorious blogger of “Not even Wrong”:

“The string theory multiverse pseudo-science has done a huge amount of damage to the interests of string theory within the academic community, but it also threatens to do damage to the understanding and image of science among the public.”

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Compare this to the statement:

Our Universe is described by the Standard Model of Particle Physics and the Cosmic Concordance Model.

Ergo, any Universe must be described by the Standard Model of Particle Physics and the Cosmic Concordance Model.

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It would be nice if this was true.

But maybe we should not be too upset if it is not.

The healthy aspect of Landskepticism

Accepting anthropic reasoning might mean that we gave up too early on a “real” explanation.

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Caveat: these valiant efforts may be fruitless if no “real” explanation exists

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- ▶ Probably everybody would be happy if a non-anthropic solution to the cosmological constant problem was found and if string theory predicted a unique solution that leads to the Standard Model of particle physics and the Cosmological Concordance model
- ▶ If no such explanation exists we might have to accept the reality of the Landscape and the ensuing loss of predictability

A final word...

I close with a quote by Steven Weinberg:

About the multiverse, it is appropriate to keep an open mind, and opinions among scientists differ widely. In the Austin airport on the way to this meeting I noticed for sale the October issue of a magazine called *Astronomy*, having on the cover the headline “Why You Live in Multiple Universes.” Inside I found a report of a discussion at a conference at Stanford, at which Martin Rees said that he was sufficiently confident about the multiverse to bet his dog’s life on it, while Andrei Linde said he would bet his own life.

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As for me, I have just enough confidence about the multiverse to bet the lives of both Andrei Linde and Martin Rees’s dog.

Thank you for your attention!

Found on xkcd

