October 7, 2019
UChicago Gleacher Center
Chicago, Illinois

Implicit Bias

Implicit Bias

Some folks feel

Implicit Bias

Some folks feel that thinking about a multiverse is unscientific

Implicit Bias

Some folks feel that thinking about a multiverse is unscientific — too much like a bad sci fi movie.

Implicit Bias

Some folks feel that thinking about a multiverse is unscientific — too much like a bad sci fi movie.

I feel that imagining a single, unique universe is unscientific

Implicit Bias

Some folks feel that thinking about a multiverse is unscientific — too much like a bad sci fi movie.

I feel that imagining a single, unique universe is unscientific — too much like the Book of Genesis.

Implicit Bias

Some folks feel that thinking about a multiverse is unscientific — too much like a bad sci fi movie.

I feel that imagining a single, unique universe is unscientific — too much like the Book of Genesis.

There is nothing that we know of — that can be described in scientific terms — that happens only once.

Implicit Bias

Some folks feel that thinking about a multiverse is unscientific — too much like a bad sci fi movie.

I feel that imagining a single, unique universe is unscientific — too much like the Book of Genesis.

There is nothing that we know of — that can be described in scientific terms — that happens only once.

We can describe galaxy formation in scientific terms — and there are many many galaxies.

We can describe star formation in scientific terms — and there are many many stars.

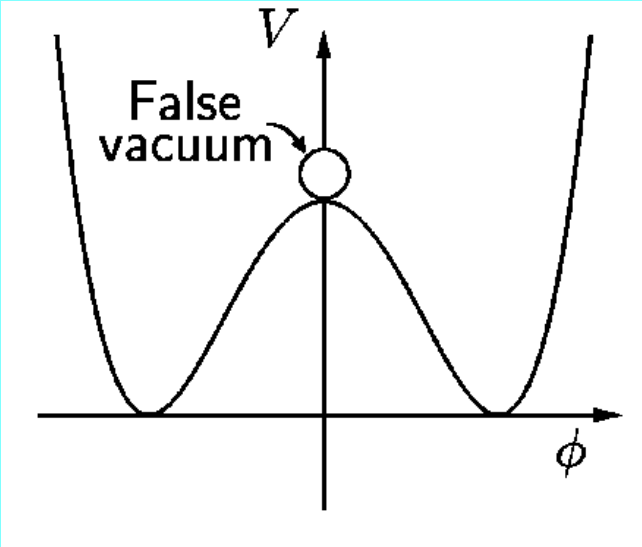
If we can describe universe formation in scientific terms — the ultimate goal of cosmology — then we should expect many many universes.

Three Winds Blowing Us Towards the Multiverse

In the past decades, three important developments have pointed us towards a multiverse.

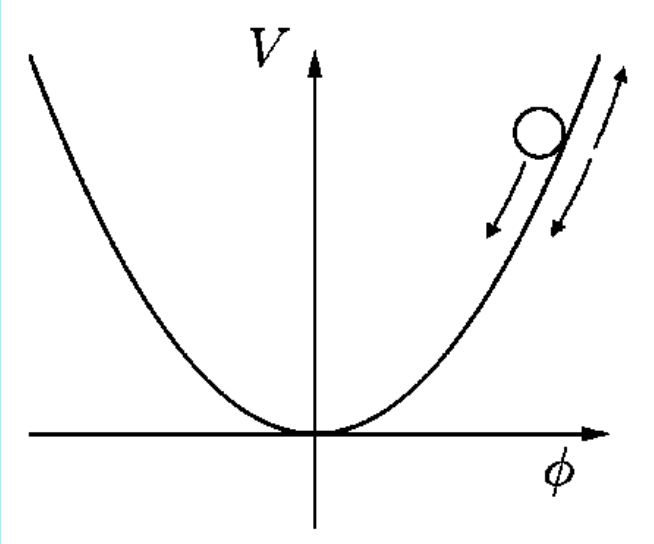
1) Almost all inflationary models allow eternal inflation:

Once inflation starts, it never globally stops. It stops in places, forming pocket universes, but elsewhere it continues.



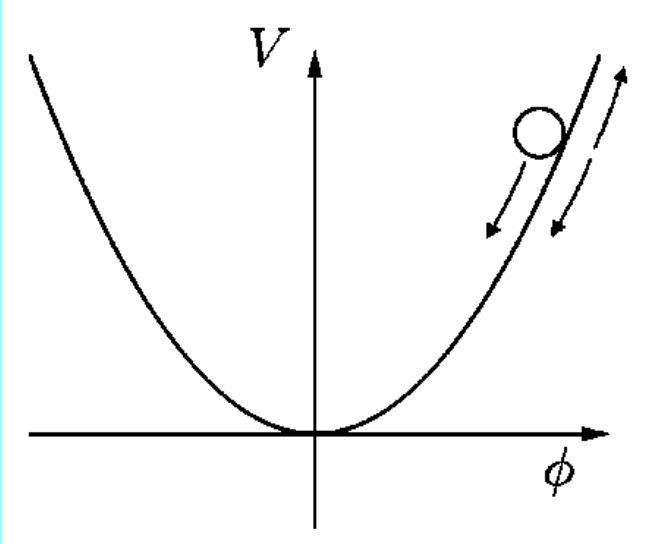
The probability to remain at the top of the hill falls off exponentially with time. BUT: in any successful model of inflation, the exponential expansion is faster. The volume of space with $\phi \approx 0$ grows exponentially with time.

1) Almost all inflationary models allow eternal inflation, cont:



(Linde, 1986): If ϕ starts high enough on the hill, inflation will be eternal. Upwards quantum fluctuations will cause the volume of space in which ϕ is high to grow exponentially with time.

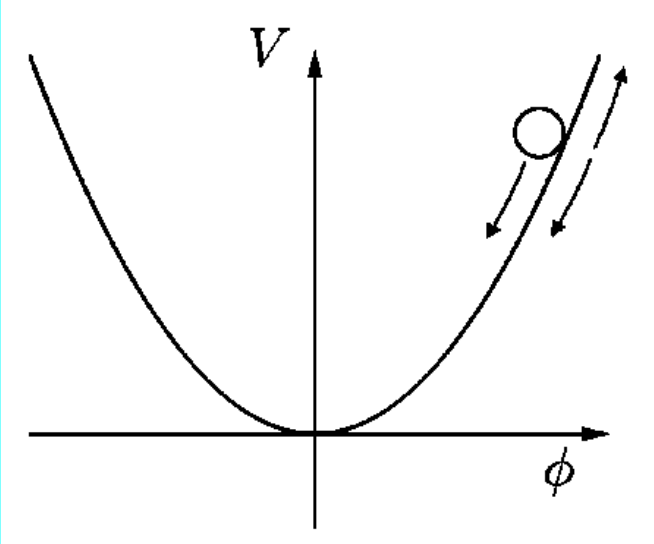
1) Almost all inflationary models allow eternal inflation, cont:



(Linde, 1986): If ϕ starts high enough on the hill, inflation will be eternal. Upwards quantum fluctuations will cause the volume of space in which ϕ is high to grow exponentially with time.

In either situation eternal inflation can be avoided if ϕ starts too near the bottom of the potential well, but both versions **ALLOW** eternal inflation.

1) Almost all inflationary models allow eternal inflation, cont:

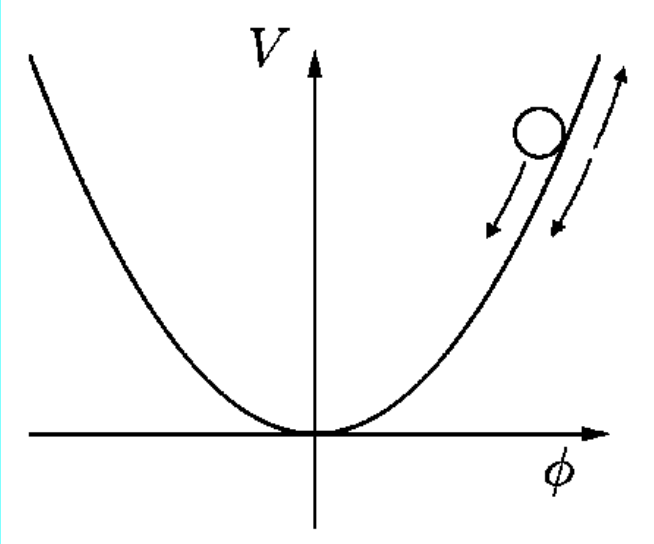


(Linde, 1986): If ϕ starts high enough on the hill, inflation will be eternal. Upwards quantum fluctuations will cause the volume of space in which ϕ is high to grow exponentially with time.

In either situation eternal inflation can be avoided if ϕ starts too near the bottom of the potential well, but both versions **ALLOW** eternal inflation.

If eternal inflation is allowed, it seems to me that it would be the only logical option.

1) Almost all inflationary models allow eternal inflation, cont:

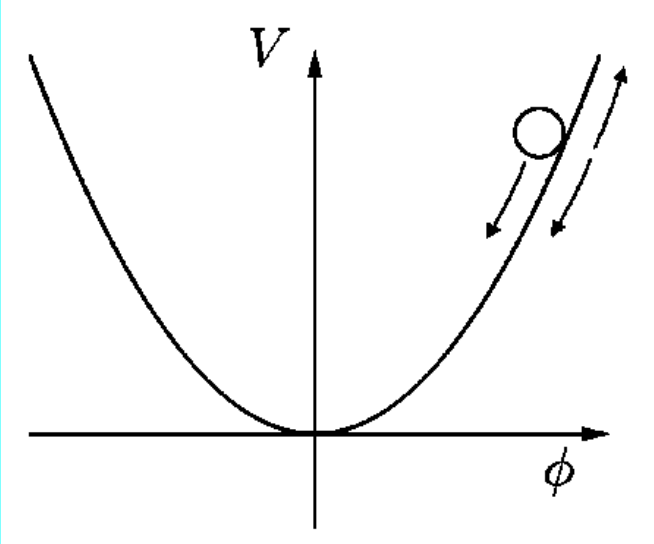


(Linde, 1986): If ϕ starts high enough on the hill, inflation will be eternal. Upwards quantum fluctuations will cause the volume of space in which ϕ is high to grow exponentially with time.

In either situation eternal inflation can be avoided if ϕ starts too near the bottom of the potential well, but both versions **ALLOW** eternal inflation.

If eternal inflation is allowed, it seems to me that it would be the only logical option. Its duration gives it an advantage over one-shot inflation by a factor of infinity,

1) Almost all inflationary models allow eternal inflation, cont:

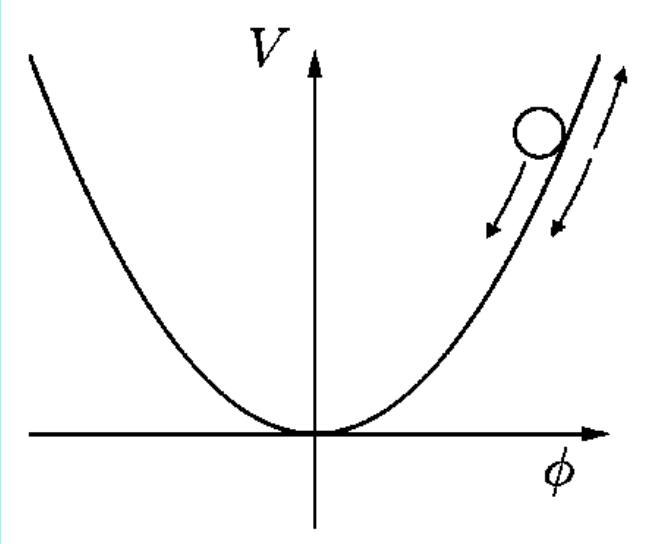


(Linde, 1986): If ϕ starts high enough on the hill, inflation will be eternal. Upwards quantum fluctuations will cause the volume of space in which ϕ is high to grow exponentially with time.

In either situation eternal inflation can be avoided if ϕ starts too near the bottom of the potential well, but both versions **ALLOW** eternal inflation.

If eternal inflation is allowed, it seems to me that it would be the only logical option. Its duration gives it an advantage over one-shot inflation by a factor of infinity, which is a large number.

1) Almost all inflationary models allow eternal inflation, cont:



(Linde, 1986): If ϕ starts high enough on the hill, inflation will be eternal. Upwards quantum fluctuations will cause the volume of space in which ϕ is high to grow exponentially with time.

In either situation eternal inflation can be avoided if ϕ starts too near the bottom of the potential well, but both versions **ALLOW** eternal inflation.

If eternal inflation is allowed, it seems to me that it would be the only logical option. Its duration gives it an advantage over one-shot inflation by a factor of infinity, which is a large number. If eternal inflation starts just once in all of eternity, we have a multiverse.

Three Winds Blowing Us Towards the Multiverse

2) Cosmic Acceleration:

Three Winds Blowing Us Towards the Multiverse

2) Cosmic Acceleration:

It was discovered in 1998 that the universe has been accelerating for the past 5-6 billion years.

Three Winds Blowing Us Towards the Multiverse

2) Cosmic Acceleration:

It was discovered in 1998 that the universe has been accelerating for the past 5-6 billion years.

Simplest explanation: Vacuum energy density $\rho_{\text{vac}} > 0$, but

$$\rho_{\text{vac}} \sim 10^{-120}\, M^4_{\text{Planck}} \ .$$

Three Winds Blowing Us Towards the Multiverse

2) Cosmic Acceleration:

It was discovered in 1998 that the universe has been accelerating for the past 5-6 billion years.

Simplest explanation: Vacuum energy density $\rho_{\text{vac}} > 0$, but

$$\rho_{\text{vac}} \sim 10^{-120}\, M^4_{\text{Planck}} \ .$$

Result: there seems to be no way to avoid the conclusion that the universe is **EXTREMELY** fine-tuned.

Three Winds Blowing Us Towards the Multiverse

2) Cosmic Acceleration:

It was discovered in 1998 that the universe has been accelerating for the past 5-6 billion years.

Simplest explanation: Vacuum energy density $\rho_{\text{vac}} > 0$, but

$$\rho_{\text{vac}} \sim 10^{-120}\, M^4_{\text{Planck}} \ .$$

Result: there seems to be no way to avoid the conclusion that the universe is **EXTREMELY** fine-tuned.

WHY?

Three Winds Blowing Us Towards the Multiverse

3) String Theory Landscape:

Three Winds Blowing Us Towards the Multiverse

3) String Theory Landscape:

String theory plus the multiverse offers a possible explanation of the fine-tuning.

Three Winds Blowing Us Towards the Multiverse

3) String Theory Landscape:

String theory plus the multiverse offers a possible explanation of the fine-tuning.

If there are 10^{500} or more vacuum-like states, with ρ_{vac} ranging from $\mathcal{O}(-M^4_{\text{Planck}})$ to $\mathcal{O}(+M^4_{\text{Planck}})$, then there will be plenty with $\rho_{\text{vac}} \sim 10^{-120}\, M^4_{\text{Planck}}$.

Three Winds Blowing Us Towards the Multiverse

3) String Theory Landscape:

String theory plus the multiverse offers a possible explanation of the fine-tuning.

If there are 10^{500} or more vacuum-like states, with ρ_{vac} ranging from $\mathcal{O}(-M^4_{\text{Planck}})$ to $\mathcal{O}(+M^4_{\text{Planck}})$, then there will be plenty with $\rho_{\text{vac}} \sim 10^{-120}\, M^4_{\text{Planck}}$.

Selection effect: if $|\rho_{\text{vac}}| \sim M^4_{\text{Planck}}$, then the lifetime of the universe is $\sim M^{-1}_{\text{Planck}} \sim 10^{-43}$ seconds.

Three Winds Blowing Us Towards the Multiverse

3) String Theory Landscape:

String theory plus the multiverse offers a possible explanation of the fine-tuning.

If there are 10^{500} or more vacuum-like states, with ρ_{vac} ranging from $\mathcal{O}(-M^4_{\text{Planck}})$ to $\mathcal{O}(+M^4_{\text{Planck}})$, then there will be plenty with $\rho_{\text{vac}} \sim 10^{-120}\, M^4_{\text{Planck}}$.

Selection effect: if $|\rho_{\text{vac}}| \sim M^4_{\text{Planck}}$, then the lifetime of the universe is $\sim M^{-1}_{\text{Planck}} \sim 10^{-43}$ seconds.

Is it plausible that no life can form in 10^{-43} seconds?

Three Winds Blowing Us Towards the Multiverse

3) String Theory Landscape:

String theory plus the multiverse offers a possible explanation of the fine-tuning.

If there are 10^{500} or more vacuum-like states, with ρ_{vac} ranging from $\mathcal{O}(-M^4_{\text{Planck}})$ to $\mathcal{O}(+M^4_{\text{Planck}})$, then there will be plenty with $\rho_{\text{vac}} \sim 10^{-120}\, M^4_{\text{Planck}}$.

Selection effect: if $|\rho_{\text{vac}}| \sim M^4_{\text{Planck}}$, then the lifetime of the universe is $\sim M^{-1}_{\text{Planck}} \sim 10^{-43}$ seconds.

Is it plausible that no life can form in 10^{-43} seconds? **I think so!**

Three Winds Blowing Us Towards the Multiverse

3) String Theory Landscape:

String theory plus the multiverse offers a possible explanation of the fine-tuning.

If there are 10^{500} or more vacuum-like states, with ρ_{vac} ranging from $\mathcal{O}(-M^4_{\text{Planck}})$ to $\mathcal{O}(+M^4_{\text{Planck}})$, then there will be plenty with $\rho_{\text{vac}} \sim 10^{-120}\, M^4_{\text{Planck}}$.

Selection effect: if $|\rho_{\text{vac}}| \sim M^4_{\text{Planck}}$, then the lifetime of the universe is $\sim M^{-1}_{\text{Planck}} \sim 10^{-43}$ seconds.

Is it plausible that no life can form in 10^{-43} seconds? **I think so!**

Life can only form if $|\rho_{\text{vac}} \ll M^4_{\text{Planck}}$. This selection effect is certainly in the right ballpark to explain the observed value of ρ_{vac}.

Does the Selection Effect Explanation Amount to Giving Up?

- A number of physicists regard an "anthropic" explanation as simply giving up.

Does the Selection Effect Explanation Amount to Giving Up?

- A number of physicists regard an "anthropic" explanation as simply giving up.
- In my opinion, the selection effect explanation is both logical and scientific.

Does the Selection Effect Explanation Amount to Giving Up?

- A number of physicists regard an "anthropic" explanation as simply giving up.
- In my opinion, the selection effect explanation is both logical and scientific. I think we all accept anthropic explanations for some facts

Does the Selection Effect Explanation Amount to Giving Up?

- A number of physicists regard an "anthropic" explanation as simply giving up.
- In my opinion, the selection effect explanation is both logical and scientific. I think we all accept anthropic explanations for some facts — for example, the fact that we find ourselves living on the surface of a planet, in spite of the fact that planetary surfaces make up an unbelievably small fraction (maybe 10^{-35}) of the volume of the visible universe.

Does the Selection Effect Explanation Amount to Giving Up?

- A number of physicists regard an "anthropic" explanation as simply giving up.
- In my opinion, the selection effect explanation is both logical and scientific. I think we all accept anthropic explanations for some facts — for example, the fact that we find ourselves living on the surface of a planet, in spite of the fact that planetary surfaces make up an unbelievably small fraction (maybe 10^{-35}) of the volume of the visible universe. Is this explained by Divine Providence?

Does the Selection Effect Explanation Amount to Giving Up?

- A number of physicists regard an "anthropic" explanation as simply giving up.
- In my opinion, the selection effect explanation is both logical and scientific. I think we all accept anthropic explanations for some facts — for example, the fact that we find ourselves living on the surface of a planet, in spite of the fact that planetary surfaces make up an unbelievably small fraction (maybe 10^{-35}) of the volume of the visible universe. Is this explained by Divine Providence? By extremely good luck?

Does the Selection Effect Explanation Amount to Giving Up?

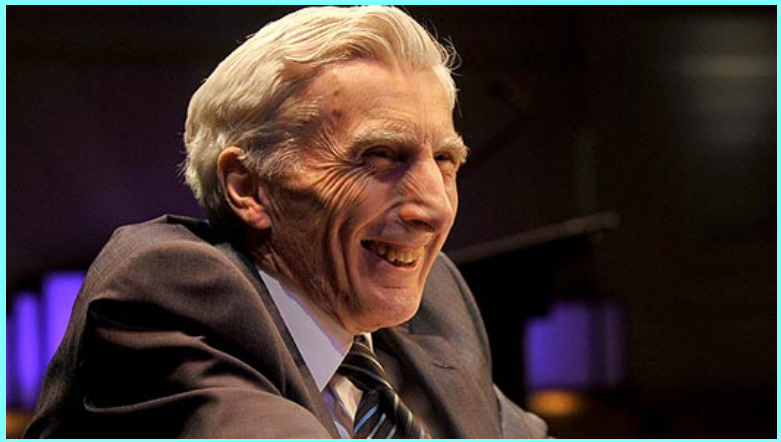
- A number of physicists regard an "anthropic" explanation as simply giving up.
- In my opinion, the selection effect explanation is both logical and scientific. I think we all accept anthropic explanations for some facts — for example, the fact that we find ourselves living on the surface of a planet, in spite of the fact that planetary surfaces make up an unbelievably small fraction (maybe 10^{-35}) of the volume of the visible universe. Is this explained by Divine Providence? By extremely good luck? Or is it a selection effect?

Does the Selection Effect Explanation Amount to Giving Up?

- A number of physicists regard an "anthropic" explanation as simply giving up.
- In my opinion, the selection effect explanation is both logical and scientific. I think we all accept anthropic explanations for some facts — for example, the fact that we find ourselves living on the surface of a planet, in spite of the fact that planetary surfaces make up an unbelievably small fraction (maybe 10^{-35}) of the volume of the visible universe. Is this explained by Divine Providence? By extremely good luck? Or is it a selection effect?
- But I would advocate that anthropic explanations be thought of as the explanation of last resort — the best evidence for an anthropic explanation is the absence of any other.

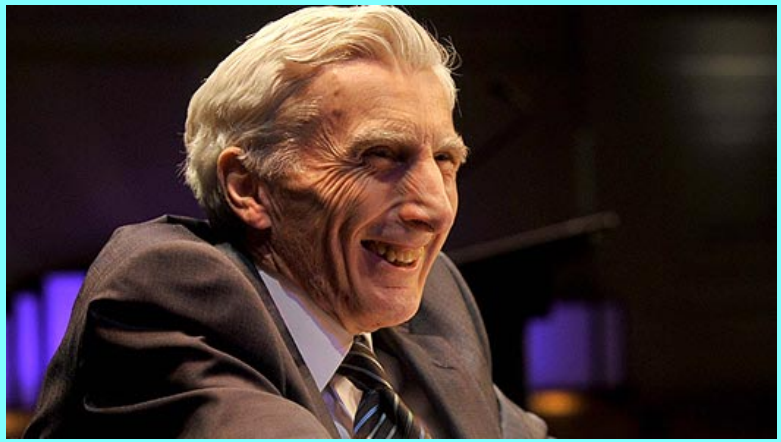
Do Physicists Take the Multiverse Seriously?

Do Physicists Take the Multiverse Seriously?



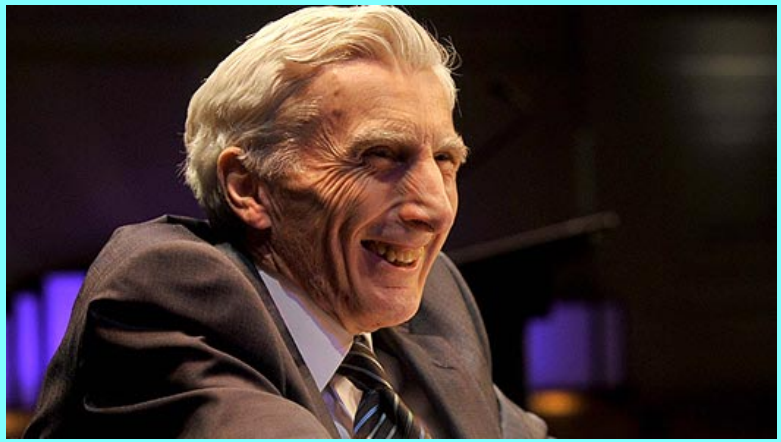
Martin Rees

Do Physicists Take the Multiverse Seriously?



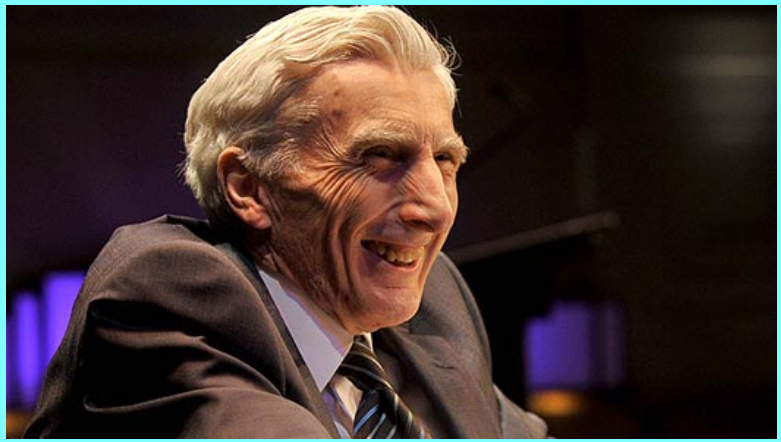
Martin Rees, the Right Honourable Lord Rees of Ludlow,

Do Physicists Take the Multiverse Seriously?



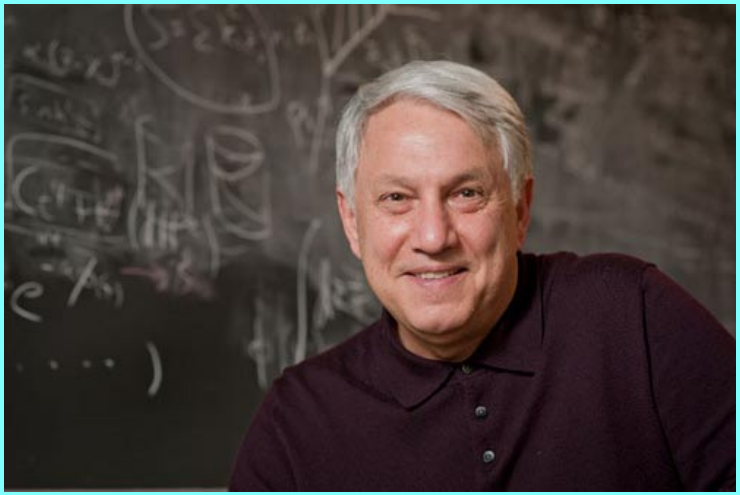
Martin Rees, the Right Honourable Lord Rees of Ludlow, Astronomer Royal of Great Britain, (former) President of the Royal Society, (former) Master of Trinity College, Gruber Prize in Cosmology, Crafoord Prize, Templeton Prize, Isaac Newton Medal,

Do Physicists Take the Multiverse Seriously?



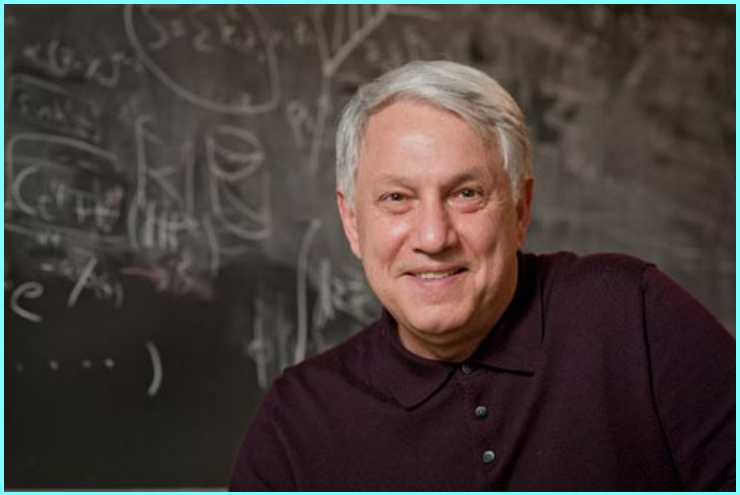
Martin Rees, the Right Honourable Lord Rees of Ludlow, Astronomer Royal of Great Britain, (former) President of the Royal Society, (former) Master of Trinity College, Gruber Prize in Cosmology, Crafoord Prize, Templeton Prize, Isaac Newton Medal, has said that he is sufficiently confident about the multiverse to bet his dog's life on it.

Do Physicists Take the Multiverse Seriously?



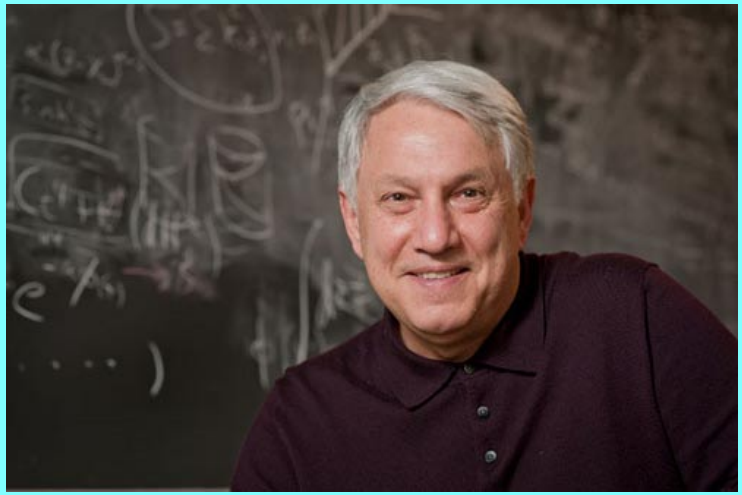
Andrei Linde

Do Physicists Take the Multiverse Seriously?



Andrei Linde, awarded the Kavli Prize in Astrophysics, the Breakthrough Prize in Fundamental Physics, the Gruber Prize in Cosmology, the Dirac medal,

Do Physicists Take the Multiverse Seriously?



Andrei Linde, awarded the Kavli Prize in Astrophysics, the Breakthrough Prize in Fundamental Physics, the Gruber Prize in Cosmology, the Dirac medal, has said that he is so confident that he would bet his own life.

Do Physicists Take the Multiverse Seriously?

Steven Weinberg

Do Physicists Take the Multiverse Seriously?

Steven Weinberg, awarded the Heineman Prize, the Benjamin Franklin Medal, the Andrew Gemant Award, the National Medal of Science, the 1979 Nobel Prize in Physics,

Do Physicists Take the Multiverse Seriously?

Steven Weinberg, awarded the Heineman Prize, the Benjamin Franklin Medal, the Andrew Gemant Award, the National Medal of Science, the 1979 Nobel Prize in Physics, has said "I have just enough confidence about the multiverse to bet

Do Physicists Take the Multiverse Seriously?

Steven Weinberg, awarded the Heineman Prize, the Benjamin Franklin Medal, the Andrew Gemant Award, the National Medal of Science, the 1979 Nobel Prize in Physics, has said "I have just enough confidence about the multiverse to bet the lives of both Andrei Linde *and* Martin Rees's dog."